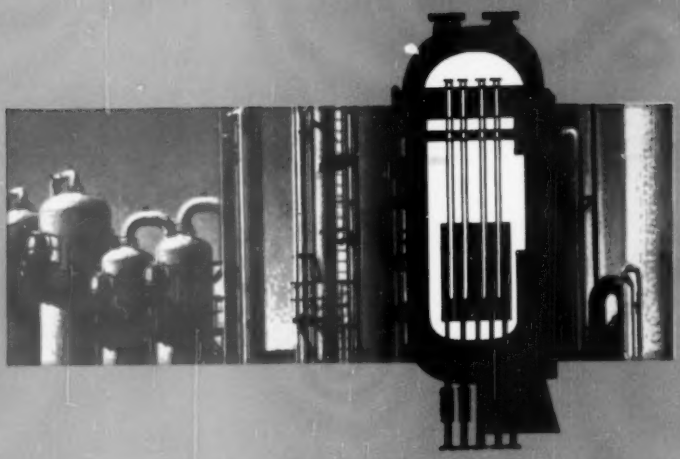
THE IDAHO ACCIDENT:
SEE PAGE 17

FEBRUARY 1961

NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION



Chemonuclear Reactors

Can fission recoil make chemicals?...

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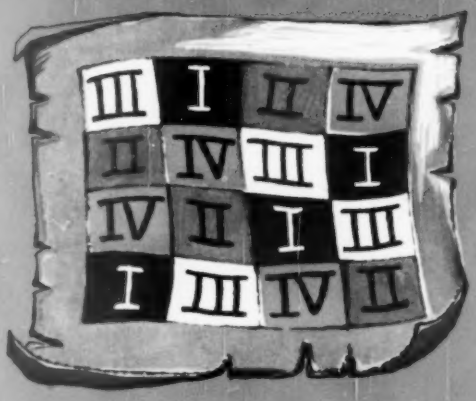

Experimental Design

Latin squares guide in-pile testing...

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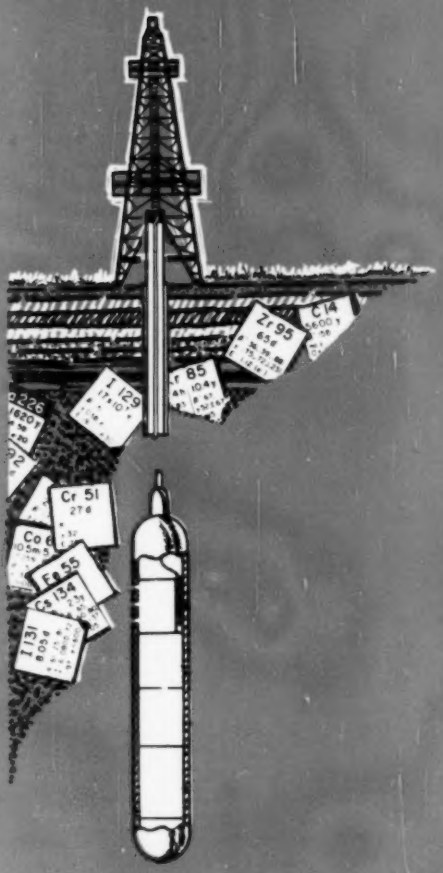

Radiotracers in Oil Wells

A review of recent advances...

p. 58

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N-4035

With 25 ma at 3500 volts, the N-4035 is designed to simultaneously provide power to a number of high gain photomultipliers. Line and load regulation are exceptional and noise and ripple in the output are kept to a minimum.

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*If this power supply is run off a regulated line, much greater current loads can be handled.

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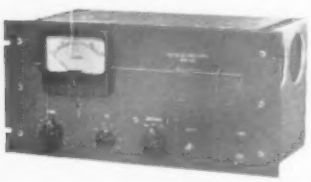

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This power supply provides 10 ma at 5000 volts with 0.005% line and load regulation and positive or negative output. Ample power is available for multicoincidence studies using 14 stage photomultipliers or other similar applications. Output voltage may be set to the nearest volt from a standard cell calibrated control. Through use of a unique design, the output is free from corona noise and ripple.

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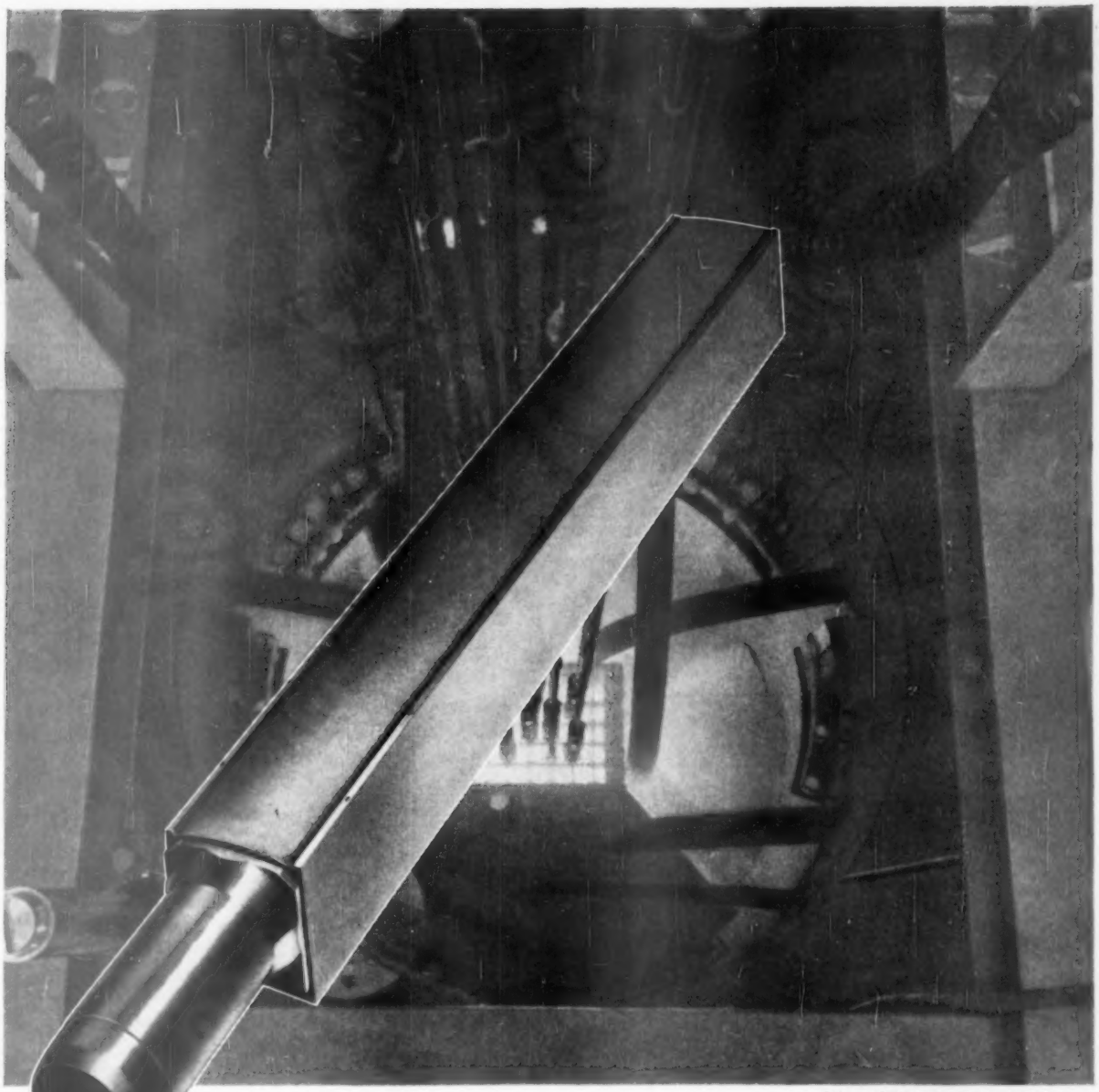

View of DR-2 core in operation.

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In Denmark, *bestilt igen* means "ordered again." Highly satisfactory performance from the first core Denmark purchased from Babcock & Wilcox for its DR-2 Research Reactor led to the recent order for a second one. The first core was operated primarily on a six day week, 24 hours a day at a full rated power of 5MW. The new core, like the first, utilizes B&W's exclusive pinned construction, and consists of thirty 90% enriched fuel elements and ten control elements.

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APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

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...about NUCLEONICS

The following item was written before the SL-1 reactor accident (see page 17), which gives it new pertinence. —The Editors

An Element of Risk

The photograph below symbolizes the element of risk that exists in all human affairs; the charred, kerosene-soaked letter shown there was received by us after being rescued from the mid-air collision of two commercial airliners over New York City last December 16. All 128 persons aboard the two airliners were killed in that tragedy, as were five more persons who were on the ground when one of the planes crashed in the crowded Brooklyn streets.

There is no question but that greater investment in air safety lessens the likelihood of such accidents. The level of expenditure for air safety was increased dramatically following the public recognition of the danger after a similar crash of two airliners over the Grand Canyon in 1956. Still more money will be spent as an aftermath of this disaster—and air travel will grow safer as a result, at least relative to the vast increase in the density of air travel that is expected. But some element of risk will remain; no expenditure can buy certainty.

CHARRED-REMINDER OF RISK. Letter rescued from jet airliner that crashed in New York City contained press release from San Francisco office of AEC.

Whether the decision is explicit or not, there is some balancing of the degree of safety that is desired against the amount of money that the Government and/or the airlines are willing to spend. While civilized society regards human life as priceless in a moral sense, our everyday life is replete with examples of how we trade the possibility of death or illness against economic considerations. The balance point varies with the situation: think of death in highway accidents vs. the cost of seat belts, the price of coal vs. expenditures for mine safety, the postulated connection of lung cancer and cigarette smoking vs. the cost of a research program to settle the controversy and an educational program to inform the public if rational judgment suggested that smoking should be curtailed.

[This matter of balance was most eloquently discussed in our pages by Canada's Ernest Siddall (NU, Feb. '59, p. 64); we will be pleased to send a reprint to any interested reader.]

Certainly the balance point for the nuclear industry has been set decisively in the direction of safety. But even for us it is just a balance point. No one should think that we have bought absolute safety; that having guarded against what we call "maximum credible" accidents, it is incredible that accidents will occur. Indeed they will occur; then, as now, it will be important to realize that all human endeavor involves an element of risk. Airplanes do drop from the sky and kill people on the snow-covered streets of Brooklyn. —*The Editors*

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COMING FEATURES

Reactors on the Line #9—YANKEE
Radionuclides Aid Blast-Furnace Operation
Carbon Steel for Reactor Primary Loops
Intense Antimony-Beryllium Neutron Sources
Nuclear Energy in Space (April)
Components for Nuclear Reactors (July)

PM-3A Will Supply Antarctic Power

Nuclear Power Plant Is Designed With Many Unique Features

PM-3A nuclear power plant (inset) will be located on the first plateau of Observation Hill at McMurdo Sound. U. S. Naval Air Facility is in foreground. (Official U.S. Navy Photo)

PM-3A, 1500 kilowatt packaged nuclear power plant under construction at the Nuclear Division of The Martin Company in Baltimore, will be delivered to the U. S. Atomic Energy Commission on November 1 of this year—within 15 months from start of contract work—for installation at the U. S. Naval Air Facility on McMurdo Sound, Antarctica.

Designed to supply electrical power for the principal base of all U. S. scientific efforts on the southernmost continent, PM-3A will be the first peaceful use of the atom in the Antarctic.

PM-3A will have many important features unique to Martin-designed systems and will meet unusual installation and maintenance requirements created by extreme weather conditions and inaccessibility:

Pre-assembled Modules for Immediate Integration. The entire plant is prefabricated at Baltimore in fully air transportable 30-foot "modules." The compact packages permit ease of handling. The modules are largely preassembled and designed so Navy personnel can erect the reactor system within 60 days after arrival at the Antarctic site and ready it for full power generation within 15 days.

Self-contained Handling and Primary Loop Support Equipment makes it possible to erect and install the primary system without special additional facilities and structures. This equipment also provides a foundation for the primary system building and gives structural support required for the fresh fuel storage facility and the primary building loading dock.

Two-year Core Life reduces energy cost and shortens plant downtime for refueling. This contributes to overall plant economy.

Fault Location Instrumentation in the control system simplifies and speeds maintenance, helps increase plant reliability, and reduces personnel training requirements.

Reactor Pressure Vessel of Austenitic Material is capable of withstanding the integrated neutron dose over 20 years, as opposed to other materials in which irradiation may raise brittle fracture temperature to levels encountered during plant operation or shutdown. It is the safest practical design.

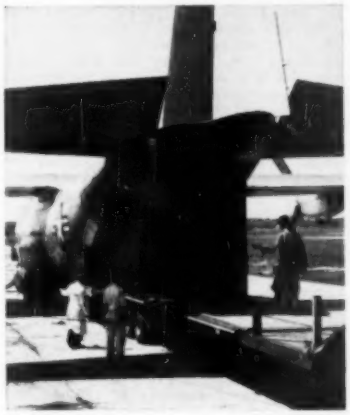
Hermetically Sealed Control Rod Actuating System eliminates dynamic seals, resulting in increased reliability and reduced water consumption.

Unit Core Loading simplifies fuel handing and cuts down refueling time. Spent core in its cask can be air transported in a single flight.

Direct Air-steam Condensers are an advancement which simplifies plant arrangement, reduces the total number of packages and auxiliary power requirements.

Containment Design is air transportable and requires no major field welding.

Completely Pre-assembled Decontamination Facility serves as both shipping container and final enclosure for decontamination equipment, resulting in reduced installation time and flexibility of plant arrangement.

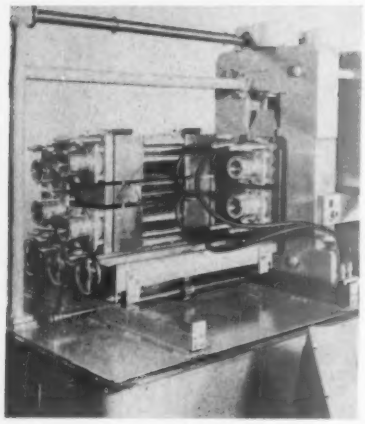


Air transportable module being loaded into C-130A aircraft.

PM-3A will increase the power available at McMurdo without requiring highly expensive transport of additional diesel fuel to the Antarctic. This dependable supply of power will enable scientists there to carry out their studies more effectively and under improved conditions.

MARTIN

NEWS FROM
LOMA



This heavy-duty, high-precision 2-high/4-high Combination Rolling Mill was recently installed at the new Fuels Technology Center of the Argonne National Laboratory. The outstanding feature of the new machine is its complete enclosure in a controlled atmosphere glovebox to allow the processing of alpha-active, pyrophoric materials, such as plutonium.

To facilitate remote control operation within the glovebox enclosure, the mill is equipped with a mechanized roll changing device comprising a roll storage car, three slideways to carry three roll assemblies, quick-disconnect screwdowns and universal spindle supports. The entire roll assemblies are readily moved into or out of the mill by turning a handwheel and are cross-transferred by moving the car along the face of the mill. Thus, complete roll changes can be performed in a few minutes without undue effort.

The new LOMA rolling mill may be operated in either a 6 in. x 8 in. 2-high set-up or a 1½ in. & 6 in. x 8 in. 4-high set-up. The 2-high arrangement is used for either hot or cold breakdown rolling of plate and sheet, and grooved rolls are also available to process rounds from 1 in. to ¼ in. diameter. In the 4-high set-up strip is cold finish rolled to gauges as thin as .002 in.

The mill is furnished with high-strength steel housings, twin-handwheel wormdrive screwdowns, universal joint spindles, herringbone gearing, and a 15 h.p. reversing variable-speed drive. The roll necks are mounted in super-precision needle roller bearings having a total separating force capacity of 175,000 lb. The bearings are continuously lubricated by an oil circulating system.

Special cartridge heating elements are mounted in the rolls to prevent undue chilling of the materials being hot worked. The heating elements are fed with current through slip rings and brushes mounted at the outboard side of the mill.

LOMA
MACHINE MFG. CO., INC.
114 East 32nd Street
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NUCLEAR REACTIONS

More Zircaloy Proponents

DEAR SIR:

In support of the Shippingport experience reported by Lustman et al. (NU, Jan., 1961, p. 58), Zircaloy fuel cladding has behaved well in the Experimental Boiling Water Reactor.

The EBWR fuel material (U–5 w/o Zr–1.5 w/o Nb alloy) differs from that of the Shippingport blanket (UO_2). The Zircaloy cladding of each, however, faces a similar corrosion and hydriding hazard in the water environment.

The EBWR has been operating since December, 1956. At times the power level has intentionally exceeded the design value of 20 Mw by a factor of three. To determine the present condition of the core, two elements were examined: element T-23, in the reactor for 1 yr, had a maximum burnup of 0.11 a/o; element ET-51, in the reactor for 2⅓ yr, had a maximum burnup of 0.39 a/o. [Details of the examination are given in report ANL-6091 (1960).]

On the basis of the examination, we offer the following comments:

1. No ruptured cladding, excessive fuel-plate warpage, swelling or corrosion is present.

2. Each fuel plate surface has at least a 5-mil surface-oxide deposit at the area of maximum heat flux. [Related aspects of EBWR experience will be discussed in articles to appear in the March issue. Ed.]

3. It is probable that isolated areas of zirconium hydride exist at the edges of the plates.

4. The core-clad bonds are in excellent condition.

5. The Zircaloy-2 cladding is still ductile.

6. At 0.4 a/o burnup, the fuel-alloy cores are hard, brittle and highly stressed.

—C. F. REINKE
Argonne National Laboratory
Argonne, Illinois

DEAR SIR:

The article "Out of the Shippingport Core . . . Zircaloy Cladding Performs Well in PWR" (NU, Jan. '61, p. 58) is outstanding. We offer our congratulations to Dr. Ben Lustman and his group for this fine presentation and to NUCLEONICS for its publication.

Controversial though this subject has been, this belated vindication of zirconium-alloy tubing as cladding material in water-cooled reactors is no surprise to those who have lived with zirconium these many years. Granting that tubular fuel elements present different and perhaps more severe conditions than those found in submarine reactors, zirconium alloy properly fabricated can meet the challenge of today's boiling-water and pressurized-water reactors.

It is the reactor of tomorrow which disturbs us most. An enormous effort has been expended in the evaluation

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and improvement of Zircaloy-2. Since the first Shippingport core, several advances have occurred such as vacuum-melted Zircaloy-2 and a low-nickel variation called Zircaloy-4. Consequently, we have today improved Zircaloy, but this falls short of the requirements of future reactors particularly since cost/kw is a most critical consideration.

The Lustman article presents the final results of the complete testing of a single alloy concept—results obtained through the concerted efforts of numerous agencies and at a cost of millions of dollars and years of effort. It is our hope that this article will spark a development program on other alloys of zirconium which will extend its use to include the economic as well as the technical demands of the future.

—A. T. McCord
Carborundum Metals Co.
Akron, New York

ERRATA

November, 1960, "Reference Data Issue"

Contents page: "β Emitters by Energy and Half-Life" was withheld and appears on p. 70 of this issue.

Page 148: PM-3A has thermal power of 9.4 Mw.

Page 181: Eq. 4 should read

$$\sigma^2(x_0) = \sum_i \left[\frac{\partial M_0}{\partial M_i}\right]^2 \sigma^2(x_i)$$

Page 184: Omit last sentence and replace with: "The rejection boundary is given by $x_0 = \bar{x} + U\sqrt{\bar{x}}$, a single count x_i being rejected if $x_i > x_0$. Table 3 provides U-values for various values of P_1 and n."

Page 186: The author's correct name is John *R.* Stehn.

Page 195: The abbreviation for element 101, mendelevium, is Mv, not Md.

Page 196: Interchange the column headings 0.04–0.06 Mev with 0.02–0.04 and 0.6–0.8 with 0.4–0.6 so that they are in order of increasing energy. The nuclides remain in the present columns.

Page 199: Macroscopic cross section of indium, element 49, is 7.30 cm^{-1}.

December, 1960

Page 29: AMF Atomics does *not* have the only private fuel-fabricating plant in Canada; Canadian General Electric has such a facility in Peterborough, Ontario.

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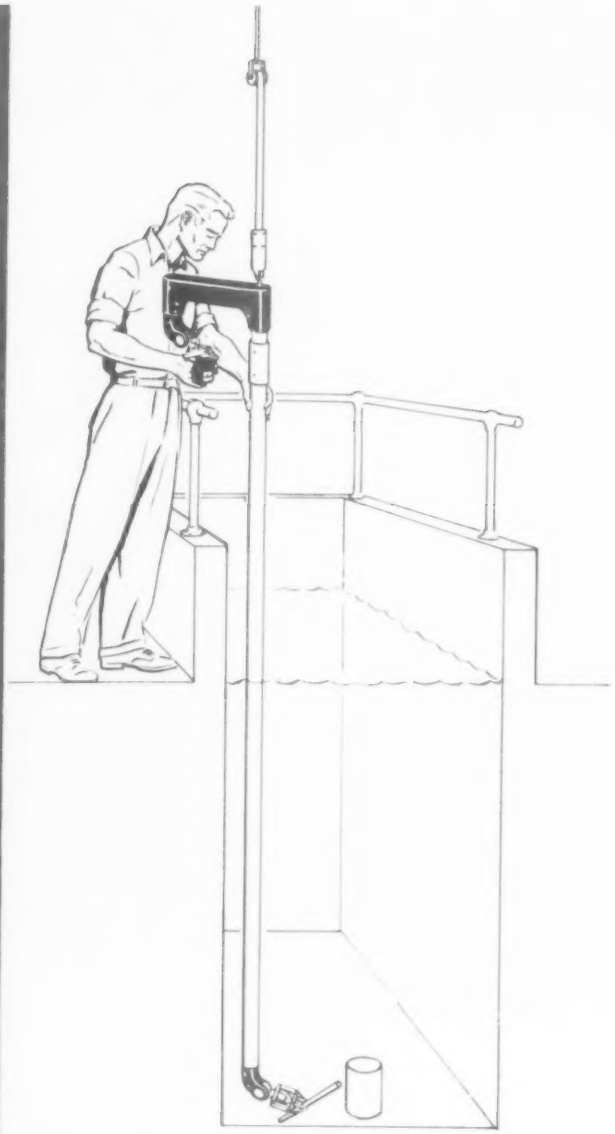

If your operation has required grappling and fishing at the bottom of a canal or pool, Central Research Laboratories' Model B Canal Manipulator may be the new tool for you. Master-Slave Manipulator type ambidextrous handle, wrist joints, and tongs are coupled by alloy tapes passing through a cross-over housing and long vertical tube. This makes possible dexterous underwater manipulation. All submerged components are stainless steel for maximum corrosion resistance.

Wrist Joint and Tong Motions

The wide range of wrist-joint and tong motions insures deft and adroit handling of large and small objects. Squeeze motion is 3 1/2 inches with an elevation rotation of 168° going from 38° back of vertical to 40° above horizontal. Twist rotation is 360° minimum at ends of elevation range, 720° when the tong is pointed 45° downward.

Azimuth rotation and X, Y, and Z translations are provided by gross movement of the vertical support tube. A constant force spring suspension supports the manipulator in the canal or pool.

For further versatility, the Model B Canal Manipulator may be equipped with standard or special purpose interchangeable tongs of either the RCD-447-100 or SRL-IIA type. Vertical tubes of desired length are available to meet most requirements.

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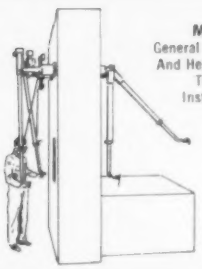

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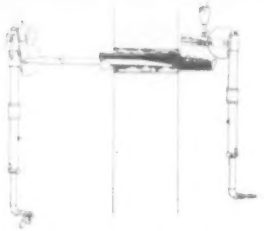

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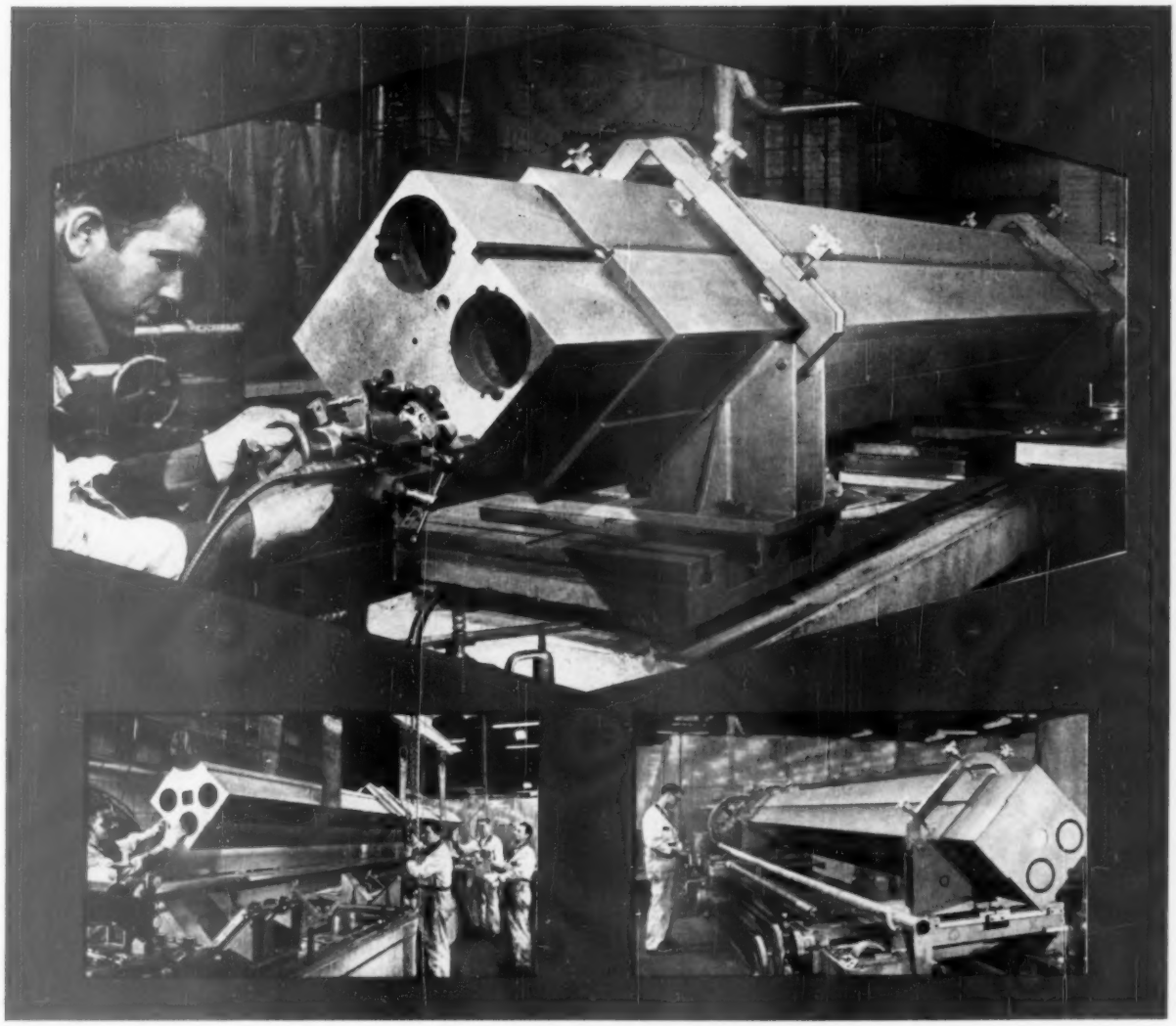

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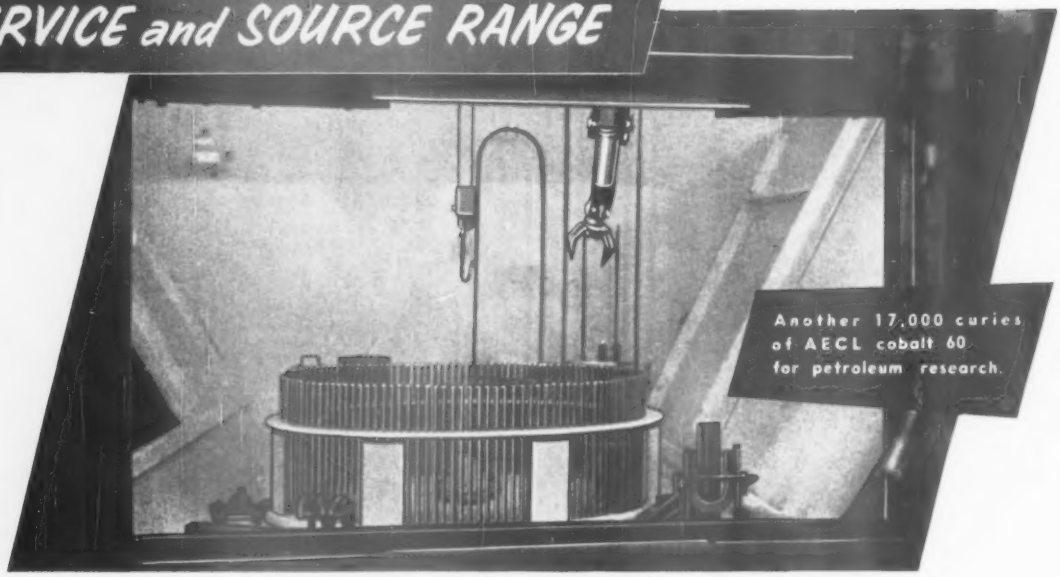

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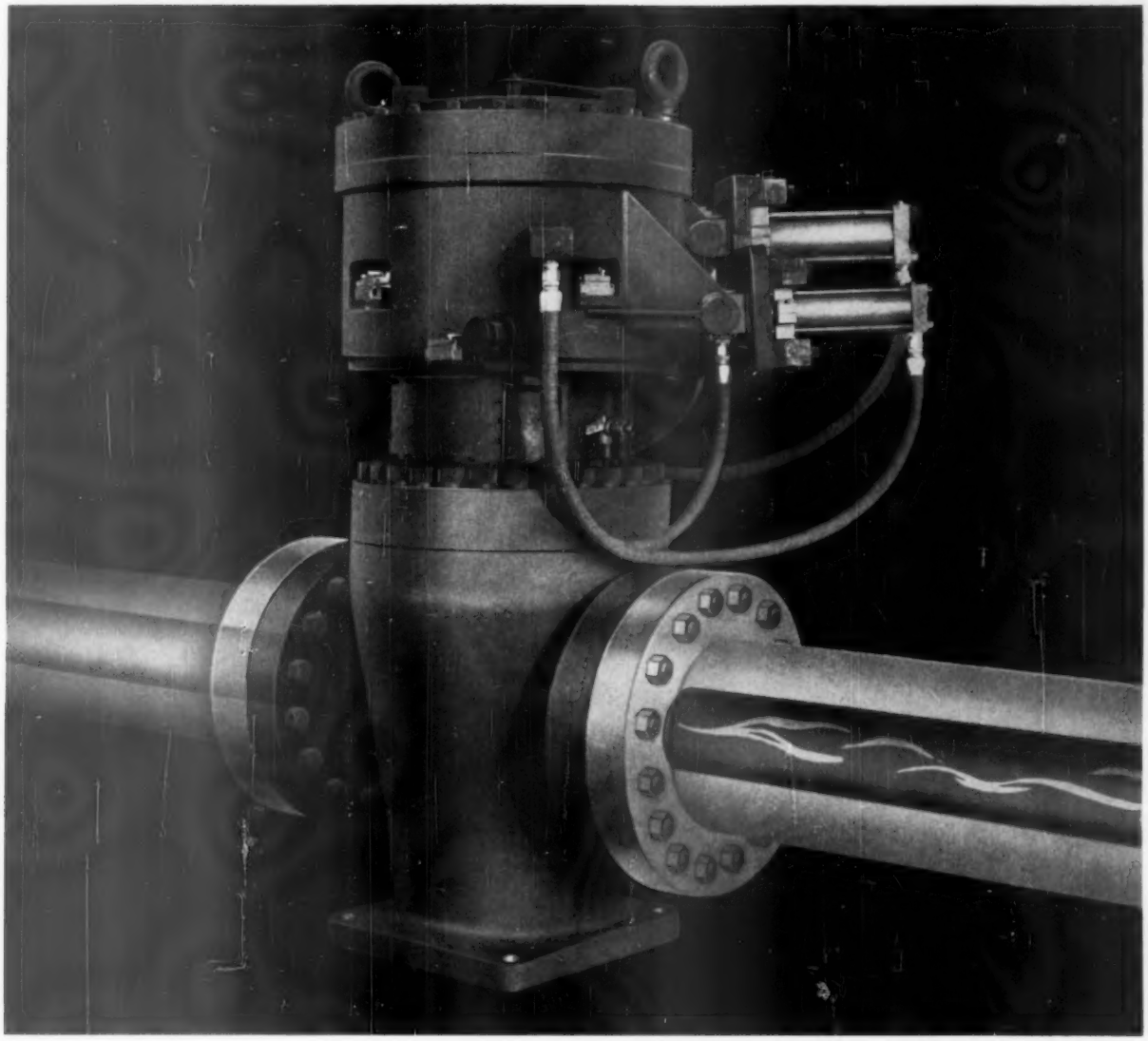

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"Putting a stop" to 2500 psi at 2500 F

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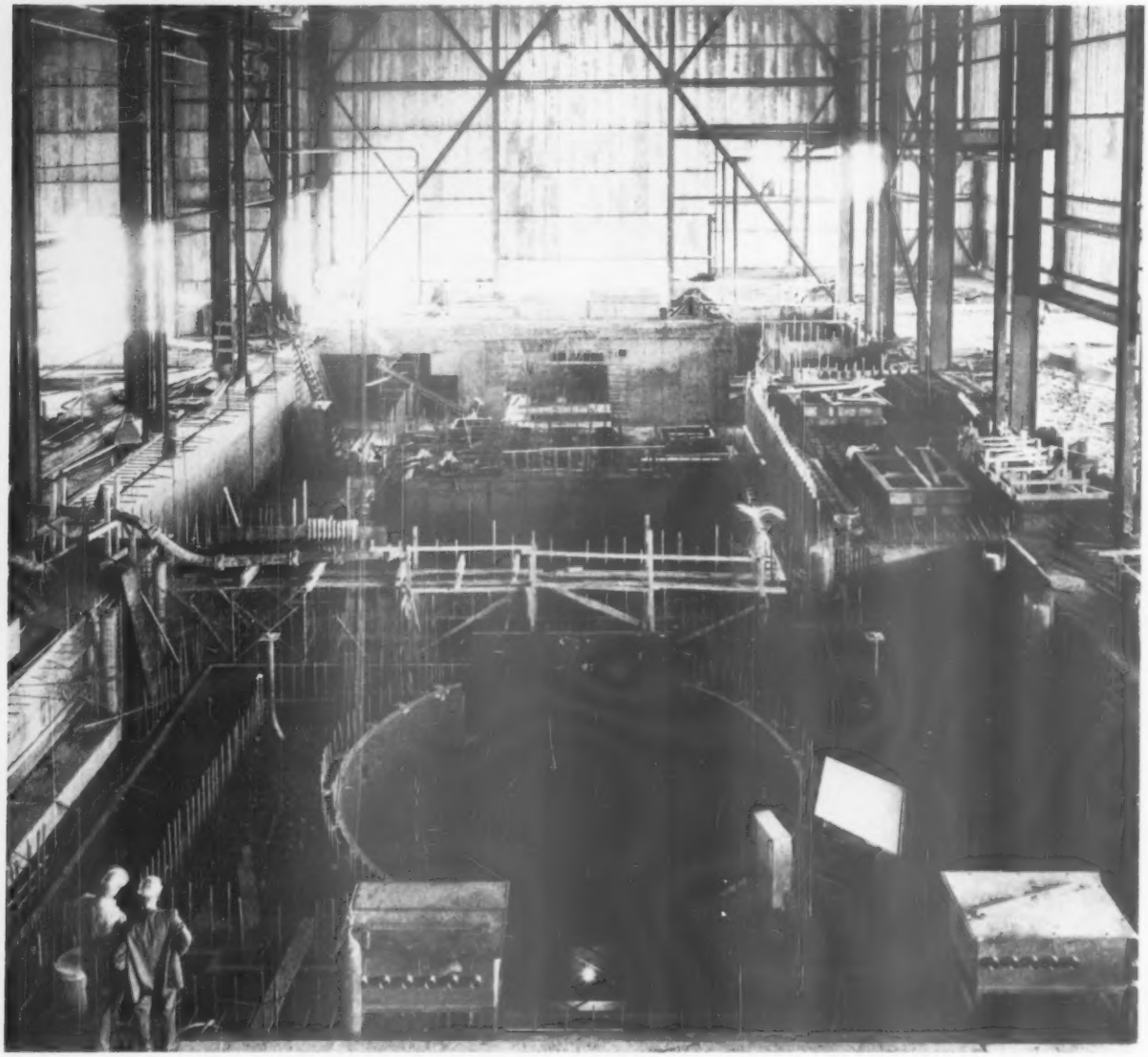
75,000 KW Sodium Graphite Reactor station for Consumers Public Power District at Hallam, Nebraska



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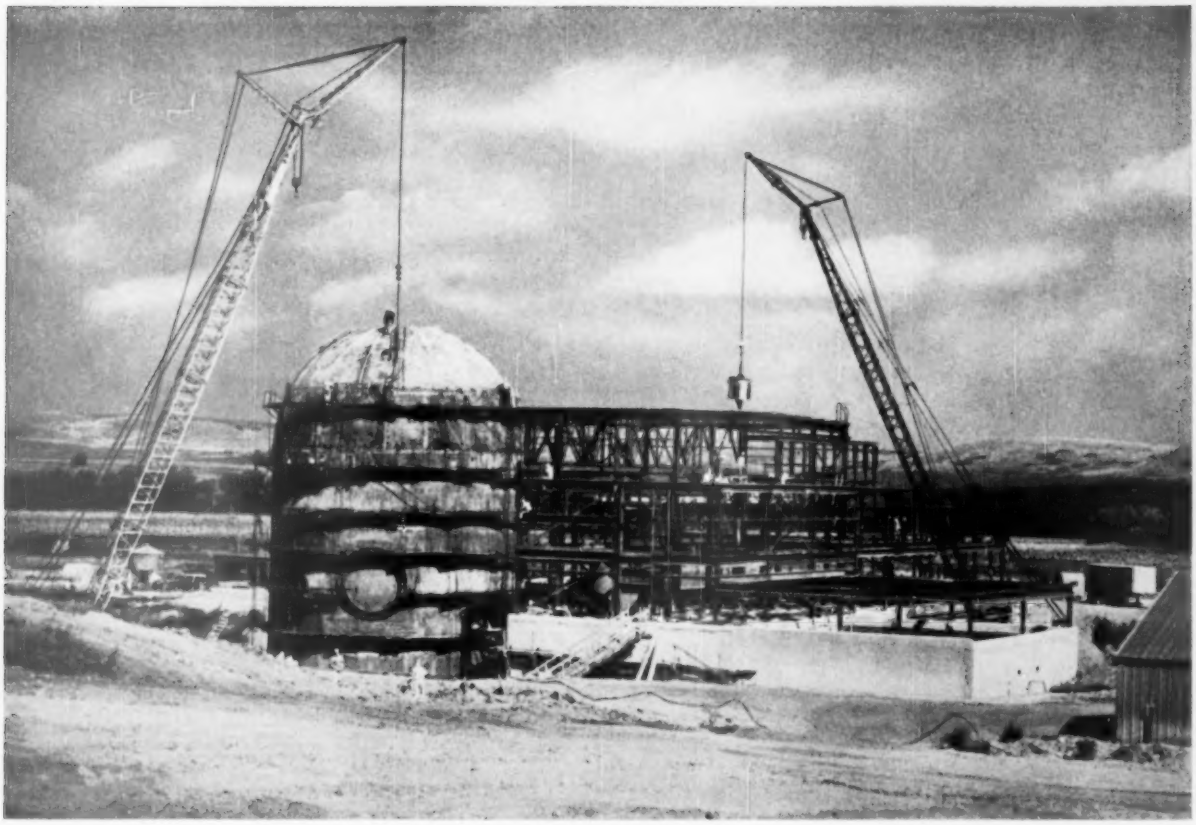

A status report:

nuclear superheat...on schedule

"Pathfinder" is the country's first nuclear superheat power station under construction. It is being built by Allis-Chalmers for Northern States Power Company. Cooperating in research and development are nine other midwest utilities* and the Atomic Energy Commission.

The above photo shows the containment, turbine, water treatment and administration buildings. Construction is on schedule.

The integral nuclear superheater will provide steam at 600 psig, 825 F. Other important design characteristics include a high power density — 46 kw per liter — and controlled recirculation — 60,000 gpm.

Only Allis-Chalmers has experience in both direct- and indirect-cycle boiling water reactors, fast breeder, gas-cooled and process-steam reactors and fusion. In addition, A-C has long been a leader in such steam plant equipment as turbine-generators, condensers, pumps, valves and water conditioning systems.

For more information about Allis-Chalmers facilities and capabilities in the nuclear power field, talk to your nearest A-C representative, or write for *Bulletin 43B9541,* **Allis-Chalmers,** Atomic Energy Division, Milwaukee 1, Wisconsin. A-1382

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Site of "Pathfinder" plant at Sioux Falls, South Dakota.

SPECIAL TUBING, under development as fuel element cladding, is filled with experimental nuclear fuel pellets in General Electric Fuel Development Laboratory.

URANIUM OXIDE POWDER is compressed into fuel elements through an experimental process of vibratory compaction.

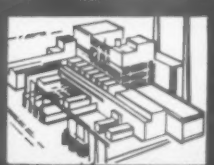
GENERAL ELECTRIC FUEL DEVELOPMENT PROGRAM AIMS TO . . .

Cut nuclear power costs one mill/kwh

A program of more than 35 separate research and development projects is now underway at General Electric to reduce the cost of nuclear fuel and thereby reduce total nuclear power generation cost. Improved fuels can cut nuclear power cost by 0.5 to 1 mill/kwh.

The fuel development program centers around continuing development of high performance, low cost nuclear fuels through reduced fabrication costs, longer fuel life, increased specific power, and the most economical fuel cycle possible.

General Electric
Boiling Water Reactor Technology
Helps Lower Nuclear Power Costs



NATURAL CIRCULATION

URANIUM ENRICHMENT ANALYZER, only one of its kind, is used for precision analysis of uranium compounds. Further development, including in-pile testing, is painstakingly conducted before production.

EXPERIMENTAL FUEL PELLET is weighed on the dust-free microbalance.

EXPERIMENTAL URANIUM OXIDE fuel pellets are removed from the high temperature sintering furnace. Stringent quality control is maintained from development to actual quantity production of nuclear fuel.

ENRICHMENT OF URANIUM compounds is determined by emission spectroscopy.

Primary emphasis is on better uranium oxide fuels for water reactors. Both in-pile and out-of-pile tests, to determine optimum fuel mix, are currently underway on cladding alloys, uranium compositions and densities, and element design prototypes.

All phases of this fuel development program are being conducted at the same General Electric facility where complete nuclear reactor systems, instrumentation, control equipment, and other reactor components are developed, designed and manufactured.

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132-10

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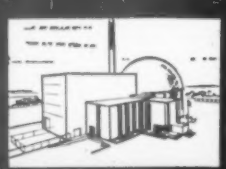
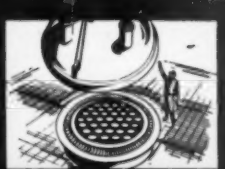


HIGH POWER DENSITY



COMPACTING

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NDA is building the Fast Burst Reactor (FBR) to provide short bursts of radiation for biomedical and health physics research at the AEC's Oak Ridge National Laboratory. The FBR is designed to generate 63 billion watts of power in 38 micro-seconds. Its 10^{17} fissions per burst is many times greater than any other pulse type reactor. The FBR will have a steady thermal operating power from one to ten kilowatts.

Employment opportunities exist at NDA on current and prospective contracts involving theoretical, experimental, design and fabrication efforts on: Reactors for Propulsion, Research and Radiation Effects/ Uranium, Thorium and Plutonium Fuels/ Molten, Boiling, Gaseous and Liquid Reactor Coolants/ Thermal, Epithermal and Fast Neutron Systems. Information about employment is available from Director, Professional Personnel.

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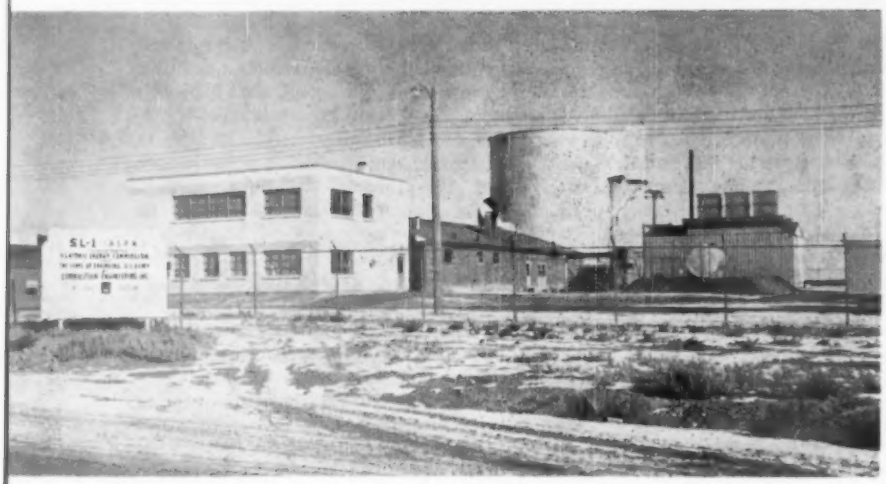
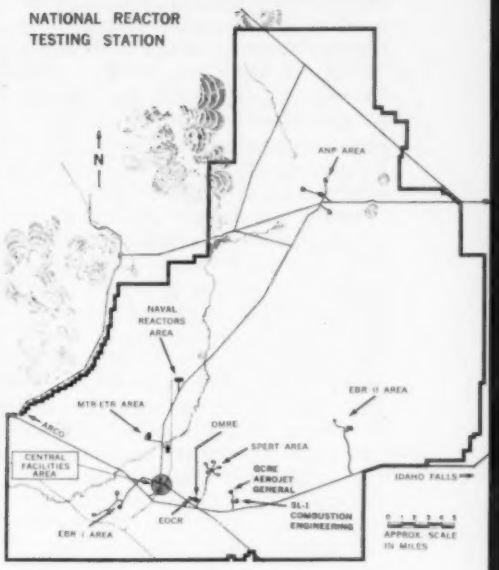




SL-1 REACTOR FACILITY as it appeared before the accident. Map shows its location in 894-sq mi National Reactor Testing Station, together with its closest neighbor, GCRE, and a little further, SPERTs, organic reactors and EBR-2

SL-1 Explosion Kills 3; Cause and Significance Still Unclear

The new year 1961 was only 69 hours old when it was marked forever for the nuclear energy community as the year of the SL-1 accident, the year nuclear reactors lost their long and jealously guarded inviolate position of never having caused a fatality.*

As of mid-January, there were two paramount questions: 1. What caused the explosion? 2. What effect will it have on the U. S. nuclear power program?

Although it will not be possible to assess fully the impact of the accident until more is known about operators' actions leading up to the moment of the explosion and the natural processes that occurred to produce it, nevertheless among industry and government leaders there were these major reactions:

• The cause of the accident when (and if) eventually determined would have much to do with its long-range effects on the use of nuclear power commercially.

• Many of those contacted pointed out that the electric utility industry has learned to accept—while continually striving to reduce and minimize—fatalities from boiler, turbine, and high-voltage-line accidents just as other industries such as the aviation, chemical and others take in their stride ordinary industrial risks.

• There was agreement everywhere—from manufacturers and utilities, from AEC, and from the Advisory Committee on Reactor Safeguards—that AEC and ACRS would move swiftly and surely to tighten up its procedures for assuring safe reactor design and operation. This was already foreshadowed by AEC's safety survey of all reactor operating licensees (*see page 23*).

• Despite this tightening, government officials generally, both in the executive and in Congress, were themselves warning against any temptation to panic. Pointing out that the nuclear industry must be prepared to accept the accidents of a developmental stage as other young industries have done in the past, one AEC official commented, "I don't think this accident will affect the industry except in a healthy way over the long term unless we let it get us down." And on Capitol Hill, the Joint Committee on Atomic Energy said it was doubtful that any special public hearings on the matter would be held this session—in part, at least, so as not to focus undue publicity on it.

* Three previous U. S. radiation fatalities (at Los Alamos) were non-reactor accidents. One Yugoslav technician died of complications after the Oct. 1958 Vinca critical experiment accident. A rumored Russian accident has never been confirmed.

1. The Accident

At 9 pm Tuesday, Jan. 3, three men were on duty at the SL-1 (Stationary Low-power Reactor No. 1), an Army Reactor Program unit operated by military personnel under the supervision of Combustion Engineering Inc. as AEC operating contractor. The reactor had been shut down for 12 days for routine maintenance and for installation of cobalt wires to do flux mapping; the three man crew, on duty until midnight, was assigned to reconnect the rod extension shafts to the cruciform control rods preparatory to going critical again the next day. At 9:02 automatic heat-detection alarms from the SL-1 went off in the three NRTS fire stations, and a radiation monitor alarmed at neighboring GCRE. When fire engines arrived at SL-1 radiation levels were dangerously high and health physicists in protective suits were called to penetrate the building. Two men were dead inside amid marks of a violent explosion; the third, fatally injured and unable to speak, died on the way to the hospital. John A. Byrnes, 22, Specialist-5, U. S. Army, had been certified as an SL-1 operator Feb. 26, 1960; Richard C. Legg, 26, Construction Electrician-1, U. S. Navy, was certified in September 1960; Richard L. McKinley, 27, Specialist-4, U. S. Army, was a trainee. All three were

high school graduates and had attended Army or Navy specialist schools.

As soon as it was light—about 10 hours after the accident—AEC sent up a plane with scintillation counters but found no airborne radiation. A chemical analysis of sagebrush downwind from the reactor building and highway traverses across U. S. Route 20, ¾ mi south of the SL-1 site, showed quite negligible or no ground contamination. At 10:45 am AEC's Idaho Operations Office issued a bulletin saying it was safe for the public to travel on Route 20.

Health physics set up field headquarters at the crossroads of Route 20 with the SL-1 access road. Late Wednesday evening a military team working in relays suceeded in recovering the body of the second victim, but it was not until 3 am Monday morning—five days and 6 hours after the accident—that the third body was recovered. It had been "lodged in the upper structure of the reactor building" above the operating floor and directly above the top of the damaged reactor, AEC said; a net had to be extended beneath the body to keep it from falling on the reactor. Yet all this had to be done by men whose stay in the building—where radiation levels were 1000 r/hr—was timed with a stopwatch. "The direct recovery was accomplished by eight men, paired in quick-moving relays to avoid excessive radiation exposure," AEC said. "No two-man team was in the building more than 65 seconds."

The bodies were taken to decontamination cells at the Chemical Processing Plant as the force of the blast had blown radioactive particulate materials into the bodies. For this reason no autopsies were made; however AEC announced that the death of the three men resulted from physical injuries sustained—that multiple injuries received at the instant of the accident were sufficient to have caused death but the level of radiation in the building would also have proved fatal. Radiation readings for the first body brought out, AEC said, were approximately: 400 r at the head; 100 r at feet; and 200–300 r over remainder of body.

Reactor Condition. The taking of observations relevant to fixing the cause of the accident was hampered not only by the almost-prohibitive radiation level within the reactor building, but also by the moral pressure on recovering the victims' bodies, with its attendant great emotional stress. With the third victim removed on Jan. 9, there came a partial relaxation for the men involved in the operation; the difficult job of determining the condition of the reactor can be pursued more slowly, more certainly, with refined equipment. As AEC General Manager Alvin R. Luedecke told a NUCLEONICS editor dispatched to Idaho Falls to report on the accident:

"We had two first tasks: to recover the victims, and to assure ourselves that the reactor is in such a condition that it can't give us more trouble. I'm anxious for us to understand what caused this accident and the Board is investigating that matter with a total effort. But those two things came first. One job is now done. The remaining one is no simple matter. We are not certain as to the state of the reactor—the water level, for example, or the condition of the core, or the integrity of the pressure vessel. Action that might seem at a glance to assure reactor safety might actually lead to more trouble. We have no reason to believe the reactor is not safe at present—we want to be certain it is safe.

"It's vital in a situation like this, with meager information and much to be done, that we act with proper urgency but not frenzy. Everyone is anxious to get the job done: it's essential that it be done with deliberation. We've got to sit down and think out each step."

Combustion Engineering officials were clearly shocked by the development. They refused to speculate on the cause of the explosion but said they doubted it was related to the corrosion of the boron strips attached to the fuel elements. "We, as operators," they pointed out, "tried to satisfy ourselves that there was always adequate shut-down margin." They also confirmed that the stainless-clad Core 2 design had been completed but that fabrication had not yet begun.

The weekly operating report for SL-1 for the week of Dec. 6–13 gives cumulative plant statistics from start of operations through Dec. 13—only 10 days before the plant was shut down routinely but, as events proved, for the last time prior to the accident. The plant had operated 10,758 hours (as against 9,109 through Sept. 30); it had been at power 9,602 hr (8,086 hr to Sept. 30); total Mwd/t was 908.6 (747); gross kwh generated 1,922,100 (1,641,700); simulated heat load, 3,089,600 (2,659,000); fuel burnup in grams of U-235, 1,144.8 (941); percent of core life expended, 39.5 (32.5).

Radiation Contained. The closest thing to a bright spot in the tragedy was the fact that outside the reactor building the radiation picture was strikingly different. This is noteworthy, as the mild-steel cylindrical structure is not even classed as a containment shell (it is not kept at a negative pressure, is not air-tight: in fact the 1959 SL-1 annual report complained of the winter heating problem on the operating floor because the cargo doors were "not tight-fitting"). Nevertheless it apparently contained the release of radioactivity from the core so well that outside it on Jan. 7, the level in the control room—in the adjacent building—was only 1.15 r/hr; 0.25–5 r/hr in most of the reactor enclosure, and an average of 156 mr/hr around the perimeter of the 350-ft-square-on-a-side enclosure (*see page 19*).

2. Emergency Organization

Many of the best nuclear brains in the country flowed to Idaho Falls in the hours after the accident, assigned —or volunteering—to help in rescue, decontamination or investigation.

In charge of all post-accident operations is Allan C. Johnson, manager of AEC's Idaho Operations Office (IDO), working closely with and reporting to Luedecke and Reactor Development Director Frank K. Pittman, both of whom were on the scene in Idaho Falls.

In addition, three special committees were named in the first week: a Board of Inquiry; a group to advise on technical aspects of decontamination and other operations at the reactor; and an ad hoc panel to advise on future use or disposition of the SL-1. The three groups are headed respectively by Curtis A. Nelson, Director of AEC's Division of Inspection; C. Wayne Bills, deputy director of health & safety, IDO; and Pittman. (*For members of each, see p. 22.*)

Objectives of the Nelson Board of Inquiry, as formulated by AEC, are: "1. Determine the nature and extent of the incident; 2. determine the cause of the incident; 3. determine the responsibility for the incident; 4. determine corrective action appropriate to minimize or preclude similar incidents." The Board met almost around the clock during the week of the accident, taking testimony from contractor, Army, AEC and technical consultant personnel, and reviewing information from the field investigations. The technical advisory committee passes on the safety and soundness of every proposed action at the reactor. The Pittman committee—like the other two a top-level group—was named at this time in order that it might now pose questions to the operating group that might affect the work of the latter. After framing such questions as it feels it

needs answered, it will probably not meet again for several months, until answers are at hand.

3. Reaction, Significance

For years, the U. S. nuclear-power program has had hanging over it the possibility—and, indeed, probability—of accidental explosion and fatality. The industry has been at once both fearful that such an accident might occur and certain, that at some time and in some place, the fact of a reactor fatality would have to be faced.

Thus, the overwhelming reaction of those contacted for comment in the aftermath of the accident was that of shock over the loss of life at SL-1. At the same time, however, it was received by many in this vein: "The inevitable has happened and should be accepted without panic—let's get on with the job."

How will the accident affect: the public's attitude toward nuclear power? the Army nuclear power program? the government's attitude toward reactor safety? the future of the boiling-water concept? the Fermi case now before the U. S. Supreme Court? and the attitude of the utility industry toward nuclear power?

Public Attitude. Most industry and governmental spokesmen felt that, because the accident took place in a remote area and because it was a small, military reactor, there would not be a substantial public reaction—unless the public were stirred up by misleading statements. Reaction of both the public and general press has been mild.

Army Program. Officials at AEC and the Defense dept. said the accident would not affect current reactor development for the Army, Navy and Air Force under the Army Nuclear Power Program. Richard Morse, director of research-development for the Army, said: "We hope we can find out the exact cause of the mishap. It's regrettable, it's unfortunate, but the accident in itself doesn't spell doom for any of our atomic programs." Col. Gordon B. Page, the Army-AEC "two hat" manager of the program, said the incident "has not changed or affected significantly any programs now in the mill."

Not clear was the possible effect on three projects still in the proposal stage: small Antarctic reactors for Byrd Station and the South Pole and a barge-mounted, non-propulsion reactor for the Army Engineers.

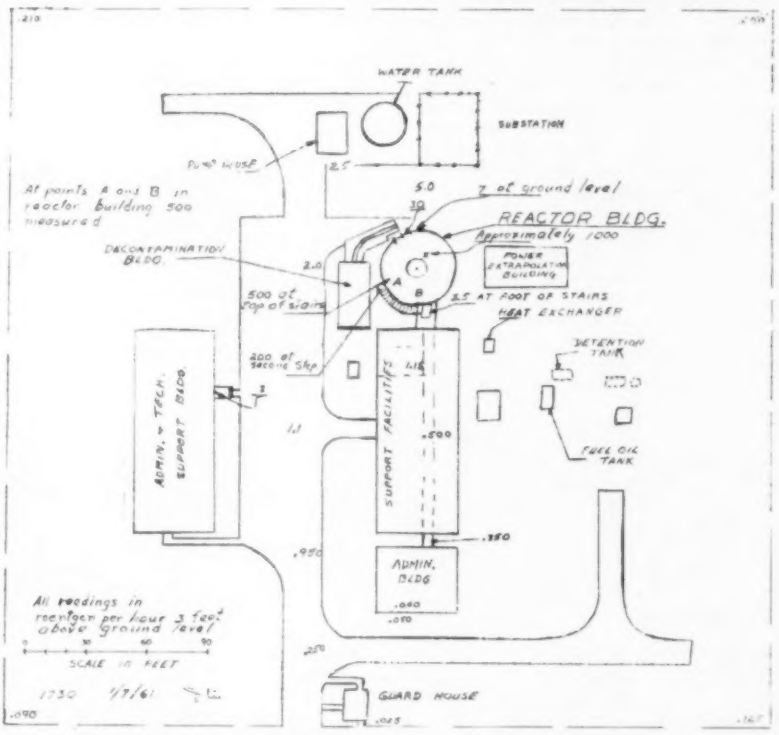
Air Force officials, who said they in no way wanted to minimize the gravity of the accident, looked on it as one of the calculated risks taken in running a defense force. It was pointed out that if a comparison of nuclear reactor accidents versus normal boiler-operation accidents were run in AF facilities alone, the lower comparative number of nuclear incidents would prevent the "panicking on power reactor development."

Reactor Safety. AEC's immediate reaction was to initiate a safety survey of all reactors and critical experiments (*see page* 23). AEC and industry officials alike shared the virtually unanimous view that steps would be taken to tighten up existing safety procedures—by both AEC and the Advisory Committee on Reactor Safeguards. The latter had reviewed SL-1 in 1958 and advised AEC, among other things, that the remoteness and low power of SL-1 assured no danger to the public. Government officials said ACRS had begun to move toward a less conservative attitude on the question of locating reactors near population centers but that the accident would inevitably "tend to arrest" this loosening up process.

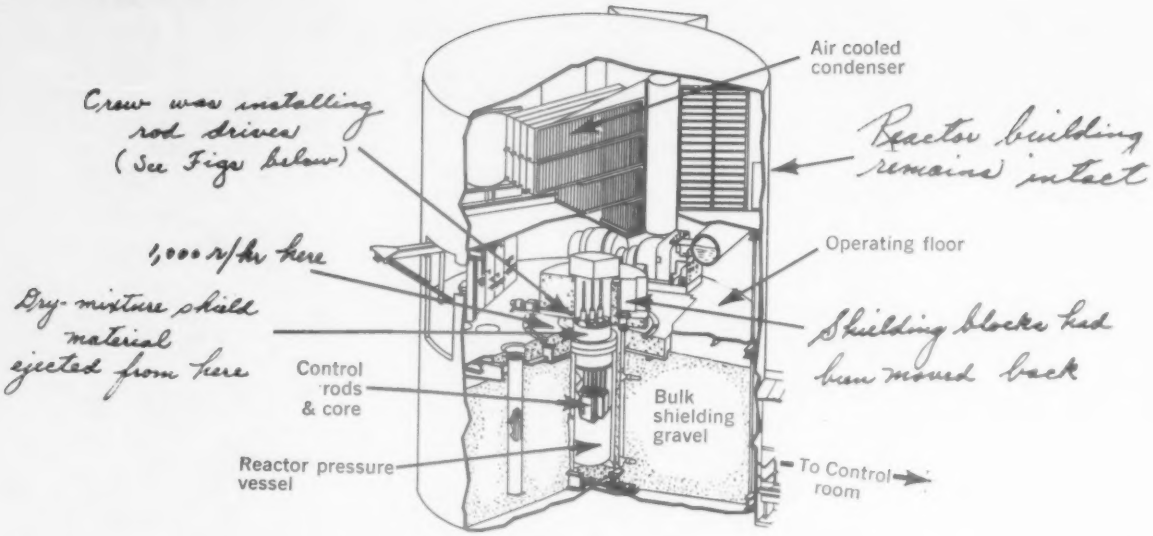
Utility Attitude. The prevailing view on the utility industry's reaction could be summed up this way: the industry can be expected to ask some searching questions of AEC, of itself and of the reactor suppliers. But, in the long run, it will probably continue to look to technically qualified people for advice on the safety of nuclear power plants. Again depending on the SL-1 circumstances as finally determined, there were few who expected the utility industry to have a strongly adverse reaction. More significant, in the view of some, was the expected tightening up of federal regulation and the negative effect this might have on utility executives considering nuclear power.

Fermi Case. A statement issued shortly after the accident by Walter Reuther, president of the United Auto Workers and the AFL-CIO Industrial Union dept., made it clear that SL-1 would be brought into the Fermi case—certainly in public statements of labor officials and, possibly, in the Supreme Court, which is expected to hear oral argument on Fermi this spring.

Following the accident, Reuther released a study of 40 reactor accidents prepared by IUD's Atomic Energy Technical Committee. "This study, plus the explosion at National Reactor Testing Station," Reuther commented, "confirmed the validity of the trade union opposition to the construction of the untested Fast Breeder Reactor near Detroit. . . . It is clear from Tuesday night's accident [Jan. 3] that thousands of people would have been over-exposed to radiation if the SL-1 reactor had been built near populated areas, just as the fast-breeder reactor is being built in its first commercial size in the Toledo-Detroit metropolitan area."

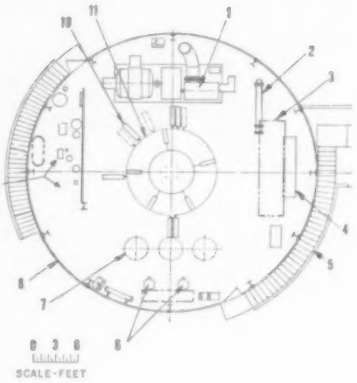


RADIOACTIVITY IN AND AROUND SL-1 shown on hand-drawn official AEC map at 5:30 pm Sat., Jan. 7. Note 500–1000 r/hr levels in building, 0.25–5 outside

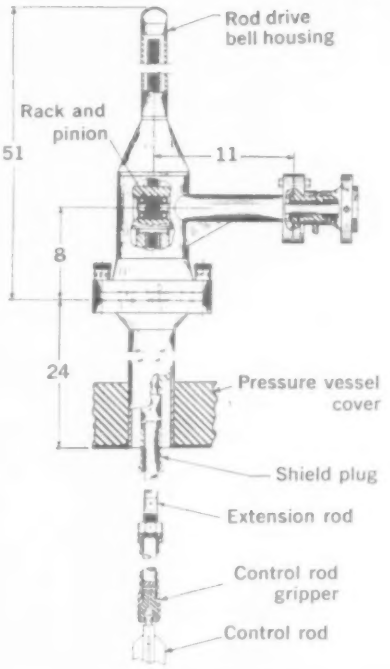

Crew was installing rod drives (See Figs below)
1,000 r/hr here
Dry-mixture shield material ejected from here
Control rods & core
Reactor pressure vessel
Air cooled condenser
Reactor building remains intact
Operating floor
Shielding blocks had been moved back
Bulk shielding gravel
To Control room

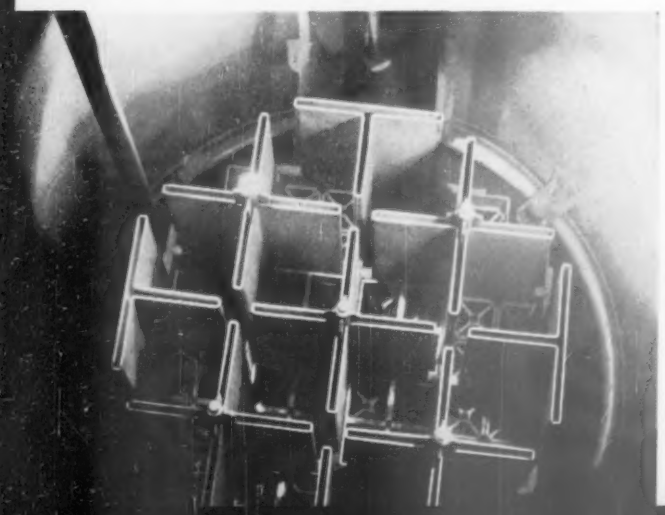
The SL-1 Reactor . . . Before Accident . . . and After

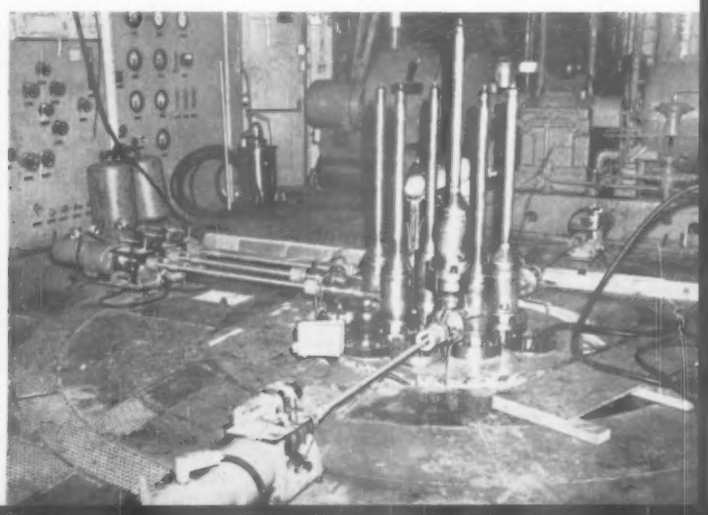
CUTAWAY OF SL-1 REACTOR (above) shows scene of accident; compare with operating-floor plan (right, center). Control-rod drive detail (far right this page) shows how bell housing around rack-and-pinion drive seats on flange above operating floor, and how control-rod gripper connects and latches to knob atop control rod in a ball-and-socket arrangement: these are the connections the victims were assigned to make on fatal night. (Below, left) SL-1 core, showing five cruciform control-rod shrouds (inside which control rods move up and down), with knobs atop rods protruding. Note fuel elements between and below shrouds in nests of four elements each; also four T-rod shrouds at sides, two of which contained cadmium strips to counteract loss of boron burnable poison, a third held experimental control rod, while fourth was empty. (Below, right) reactor top on operating floor level, before accident, with top shield removed for access to rod drives. Taller bell housing is for center, regulating, rod; four peripheral ones (two on each side closest to it) are shim rod drives. Sixth rod, furthest left, ran an experimental dummy control rod made of zircaloy so as to have no effect on the core reactivity. Note water purification panel at upper left, visible also in post-accident photo (facing page, top right)

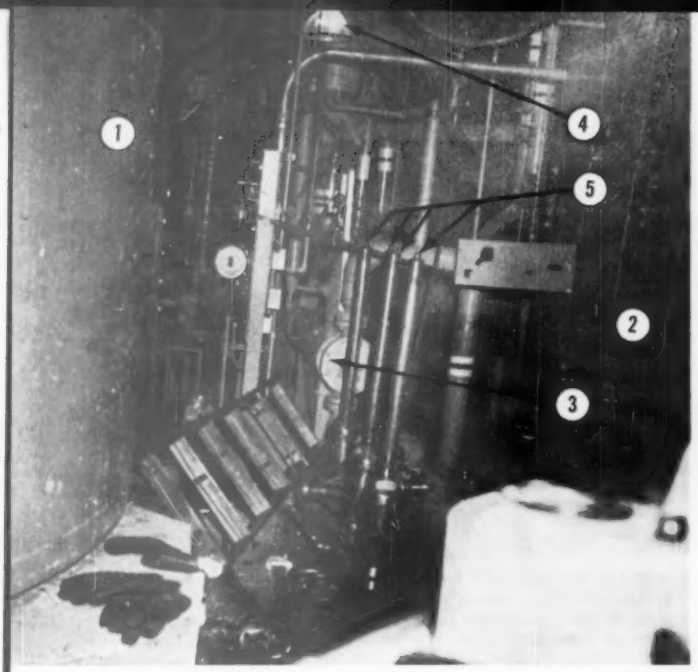


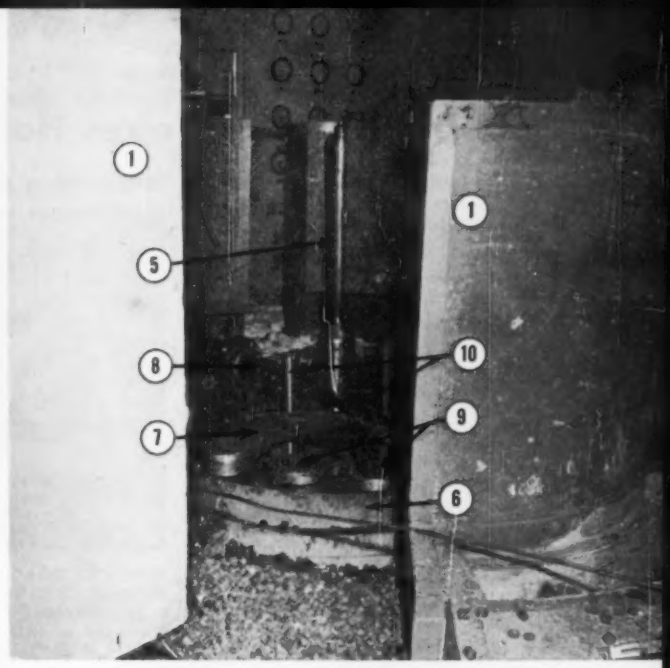
1. Turbine-Generator
2. Heat exchanger
3. Water storage tank (overhead)
4. Motor control board
5. Covered stairway
6. Feed water pumps
7. Fuel storage wells
8. Cargo doors
9. Purification system area
10. Control rod drive motors
11. Concrete shield











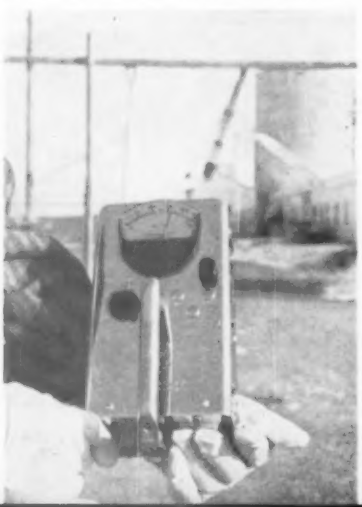
First Photographs of SL-1 Aftermath

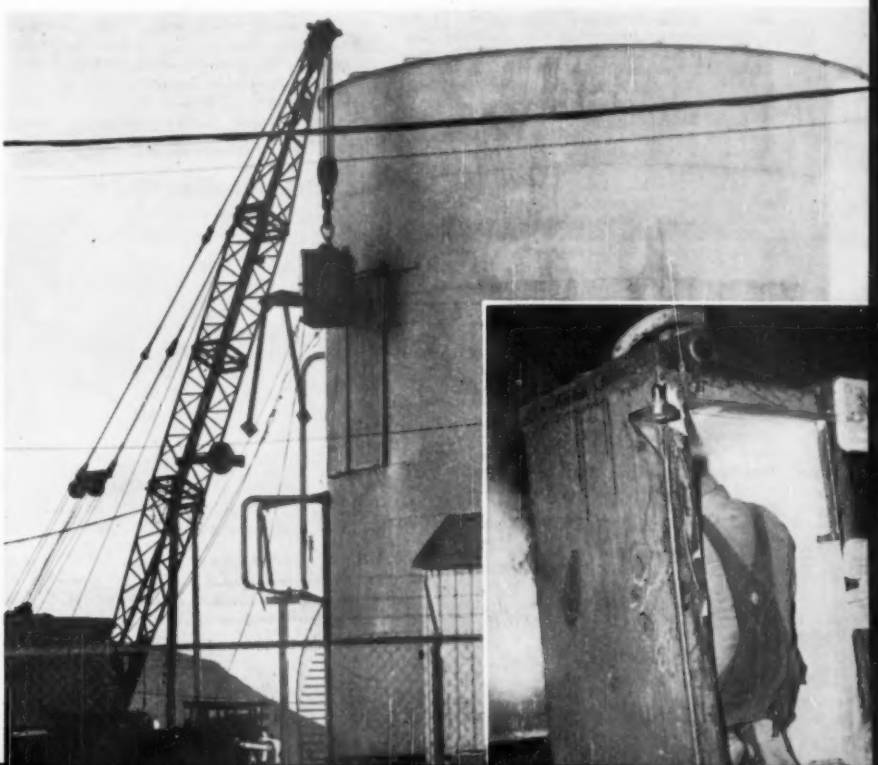
AT LEFT IS THE VERY FIRST photo taken inside SL-1 reactor building after accident. It was taken Jan. 5 by a photographer—accompanied by a health physicist—who raced up enclosed stairway from control room to reactor operating floor (point A on map, p. 19). 1 is a reactor top shield block; 2, motor control board; 3, heat exchanger for simulated heat load. Crowded condition of operating floor plus intense radiation (500–1000 r/hr) made post-accident operations extremely difficult. Little damage is visible. Note overhead lamp still working (4)—heat and electricity remained functional after accident. Ladder was knocked over in post-accident effort. Gloves are presumed to have belonged to victims. Four control-rod rack bell housings await installation at 5 (middle two blend together so that there appear superficially to be only three).

TAKEN TWO DAYS LATER, late Jan. 7, photo at right shows condition of reactor top after accident. It was taken from point B (map p. 19) few steps further in looking to left, under similar conditions. Ejected shielding punchings on operating floor and a toppled control-rod shield plug (or thimble, 8) contrast with unbroken meter glasses on water-purification panel in background as evidence of spotty damage typical of partially-confined explosions. Shielding blocks (1) are two of several forming a circle moved back when access to control rods or core is required. Scattered steel punchings formed—with gravel and boric oxide—the dry-mixture shield above pressure vessel head (6). A thin-gage cover above it (7) was bent up by force of punchings propelled upward by explosion. Beyond is bell housing for control rod rack No. 5. At (8) is control rod extension shaft still fitted within its shield plug; it would seem that this extension shaft is bent or broken (at a point obscured by shield block at right) since shaft, if intact, would be too long to fit across the circle on which it lies. Note, too, that flange of shield plug is bent (at its top left, as if it had struck I-beam overhead). That reactor is now vented to atmosphere is clearly indicated by the two open penetrations (9); whether they were open at time of accident is not known. Note also two racks (of rack-and-pinion rod drive) at 10.

SURVEY METER (below) reads 160 mr/hr at perimeter fence on Jan. 7 near SL-1 reactor building (seen in background). Dial is calibrated from 0 to 250 in multiples of 50.

CLOSEUP OF EFFORTS (right) to remove end of monorail crane prior to removing third body by crane through cargo door. Radiation levels here were 30 r/hr; operation was done from lead-shielded box with 6-in. lead window, armholes, and it was practiced in detail beforehand (inset).





AEC: Deliberation Takes Hold; 3 Advisory Units Working

As the initial shock of the accident began to wear off in mid-January, an attitude of deliberation began to take hold at AEC. First post-accident action was to ask all operators of reactors and critical facilities to furnish by end-January a report on their safety programs and procedures (opposite page); a similar survey was being made of AEC's own reactors. AEC officials were indicating that additional moves of this sort could be expected—dependent primarily on the results of its reactor surveys and on the causes of the accident.

At Idaho, as of late January, AEC was mustering plans and equipment for work within the reactor, forced to proceed cautiously because of uncertainty of the core's condition. On Jan. 19, AEC confirmed that a reactor excursion had taken place, but was withholding any statement on the cause of the accident until more evidence becomes available.

On Capitol Hill, Congressional officials were stating unequivocally that no special public inquiry would be scheduled by the Joint Committee on Atomic Energy. JCAE expects to get oral reports from AEC as the investigation progresses but the feeling seemed to be that more harm than good might be done by conducting a formal series of public hearings. On Jan. 17, AEC released this status report on the accident:

"Investigation into the cause of the Jan. 3, 1961, accident at the SL-1 in Idaho continues to be slow and difficult because of extremely high radiation levels in the reactor building which impede efforts to obtain reliable data from instrumentation or visual observation as to the present condition within the reactor itself.

"Strong indications, while not conclusive, are that the reactor, located at AEC's NRTS near Idaho Falls, sustained a nuclear excursion. Evidence is not sufficient to indicate whether or not there may have been an explosive chemical reaction. So far as it has been possible to determine, a nuclear reaction is not going on in the reactor at this time, but a complete examination has not been possible. Investigations of the reactor will, of course, be conducted cautiously to guard against the remote possibility that the investigation itself could initiate a nuclear reaction.

"Concrete shielding blocks surrounding the top of the reactor prevent study of the reactor from outside the building. Attempts are planned to view the interior of the reactor through nozzle openings or ports in the metal plate which serves as the top of the reactor vessel. Until the interior condition of the reactor is known, it cannot be determined with certainty what steps must be taken. Shielded television and photography appear to be the best methods of obtaining the initial information needed.

"Aerial and ground monitoring continues to affirm that airborne radioactivity is being confined largely to the reactor building and the immediate vicinity. Direct radiation from the reactor building has shown no increase since the accident. Calculations from direct radiation readings are as follows: 1.1 roentgens/hr at 100 ft; 0.037 r/hr at 500 ft; 0.009 r/hr at 1000 ft; and 0.002 r/hr at 2000 ft.

"Aerial and ground surveys will continue to evaluate any possible radiological hazard beyond the immediate vicinity of the reactor area building."

Determining Accident Cause

PRINCIPALS IN ACCIDENT INQUIRY are (seated, left to right): H. K. Shapar, D. I. Walker, W. Nyer, C. K. Beck, E. B. Johnson, C. A. Nelson, J. H. Sterner; and (standing) W. K. Ergen, F. Western, P. A. Morris, B. Lustman. Walter, Beck, Nelson (chairman), Western and Morris are members of the Board of Inquiry; the others are consultants or advisers. Nelson is director of AEC's Inspection div., which, by law, is charged with observing compliance with the 1954 Act and AEC's regulations

In Charge of Day-to-Day Work

DIRECTING ALL OPERATIONS AT SL-1, with responsibility for all steps taken in recovery effort, is Idaho Operations Manager Allan C. Johnson, with advice from this Action Group. (Left to right, seated): J. Anderson, Johnson, C. W. Bills, D. R. deBoisblanc, R. O. Brittan, K. Z. Morgan, M. Levenson, F. W. Thalgott. (Standing): D. H. Shaftman, J. R. Dietrich, W. C. Lipinski, W. Burgus, W. L. Ginkel, S. McGarry, J. R. Horan, V. V. Hendrix, M. C. Corbett. W. Allred, SL-1 project manager for Combustion, was absent when picture was taken. Action group develops information needed for Johnson to make decisions on how Combustion, as operating contractor, should proceed. Evaluating proposals for Action Group is a Technical Advisory Committee within it, composed of Bills (chairman), deBoisblanc, Brittan, Morgan, Levenson, Thalgott, Shaftman, Dietrich, Lipinski, Burgus

Advising Whether SL-1 Can Be Repaired

ALREADY AT WORK ON SL-1's FUTURE use or disposition is an advisory committee chaired by F. K. Pittman, AEC's reactor development director. (Left to right): L. Squires, R. L. Doan, H. M. Parker, Pittman, J. A. Swartout, S. Lawroski. Members E. P. Wigner and T. J. Thompson were absent when picture was taken

What Caused the SL-1 Accident?—Some Educated Guesses; AEC Telegram Reflects Some of Its Ideas About Cause

Only the AEC's official Board of Inquiry has the information necessary to reconstruct the SL-1 accident, and, as of Monday, January 23, even it didn't know for certain—or at least wasn't saying for publication. But many in the nuclear industry were conjecturing as to possible causes; to guide the conjectures of its readers, NUCLEONICS here presents some of its own qualitative thinking about causes. Also appended is a telegram that AEC sent to reactor licensees which reflects some areas of concern to the Commission.

It seems likely from the fact that the SL-1 reactor had been shut down without incident for 12 days before the accident and from the fact that the victims were connecting the control-rod extension shafts that the accident did not arise spontaneously but relates to the work being done on the control rods. One can hypothesize that for some reason one of the control rods was withdrawn manually (the control-rod drive motors were not hooked up) a distance sufficient to make the reactor critical. This *should* have caused the reactor to heat up, eventually shutting itself off because of the negative temperature coefficient of reactivity. But this didn't happen—the reaction reached explosive proportions.

The need to invoke more extreme Borax-type shutdown mechanisms is one of the real mysteries of this accident. It would take the very sudden removal of rather large amounts of negative reactivity to cause an explosive excursion (in the one explosive excursion of the 1953–54 Borax test, 4% of reactivity was removed in 200 milli-seconds by means of spring-driven control rods). One way to have gotten this sudden reactivity change in SL-1 was to have had the control rods that were not yet connected blown out of the core by a rush of heated water and steam following the first manual control-rod movement. And indeed post-accident photos show at least two rods connected only to their extension shafts and at least one other shield plug plus extension shaft blown out of core.

Another, less likely, mechanism is for the reactor to have lost, in one sudden surge, much of the boron poison that was distributed in aluminum-nickel strips attached to the sides of each of the fuel elements—these had been corroding at an appreciable rate for some months.

Meanwhile, AEC indicated some of the mechanisms possibly pertinent to the SL-1 accident it is concerned about in a telegram sent in mid-January to 47 reactor and critical facility licensees: Asking for a reply to its questionnaire within 30 days, AEC asked its licensees to furnish the following information:

"1. Maximum excess reactivity of your reactor, not including the worth of control rods or other control devices such as burnable poison strips or soluble poison, or any experiments, and variation of excess reactivity over core life.

"2. Total control-rod worth.

"3. Minimum shut-down margin, both at room temperature and operating temperature.

"4. Maximum worth of single control rod of highest reactivity value.

"5. Description and worth of other methods used for controlling reactivity such as burnable poison strips or soluble poison and variation of the worth of these methods over core life.

"6. Maximum total and individual worth of any fixed or movable experiments inserted in your reactor.

"7. With respect to items 1–6 above, the following information should be included: basis for reactivity values, (measured, calculated or estimated); condition of core for which values are applicable (operating or shut down, amount of burnup); and dates on which reactivity values were last determined.

"8. The following information with respect to operations which could involve changes in core reactivity when the reactor is shut down: a. special precautions taken to prevent inadvertent criticality; b. whether nuclear instrumentation is used; c. methods used to limit and control rate and amount of reactivity changes; d. minimum amount that reactor is subcritical during such operations and how the subcritical margin is achieved; e. whether such operations are conducted under direct and personal supervision of technically qualified and designated supervisors; f. whether such operations are conducted in accordance with written procedures. Reports should be submitted in 15 copies."

[Ed. note: For SL-1 foldout published NU, Feb. '59, contact Readers' Service Dept., Nucleonics—$.25 copy.]

Thorium Reprocessing Plant for Italy Designed by Allis

Title I design for a thorium reprocessing pilot plant now lies completed atop a drawing desk in the offices of Allis-Chalmers' Washington group, carried out under a year-old joint program with Italy's CNEN (Comitato Nazionale per l'Energia Nucleare, Italy's recently-established AEC).

The four-year program to delineate the technical feasibility and economic advantages of the thorium fuel cycle links a nearly-completed U. S. reactor—the Allis-built Elk River reactor fueled with ThO_2-UO_2—with Italian interests to piece together an integrated operation including reactor, reprocessing, and fuel-fabricating facilities. Operation of the reprocessing plant is expected by mid-1963.

If the program succeeds, Allis would become the first reactor manufacturer able to offer a complete, commercial nuclear power package based on the thorium cycle.

Allis' cost-plus-fixed-fee contract with CNEN covers four phases: Under Phase I, preliminary design of the reprocessing plant has been completed and cost estimates are now nearing completion; a development program is underway in support of the design, based on the Thorex solvent extraction process, and reactor evaluation to provide the Italians with the background to select a suitable line of thorium-burning reactors. Phase I of the contract, ending April 15, 1961, is worth $350,000. Phase II embraces detailed design of the pilot plant and continuation of the development and reactor-analysis programs. Phase III includes site preparation (location still to be chosen by CNEN) and an early-'62 construction start for mid-'63 completion. Phase IV covers operation of the reactor, reprocessing and fuel-fabricating plants as an integrated fuel system. Results of this phase will lead to determination of firm cost bases for the ThO_2-UO_2 system and demonstration of the feasibility of remote refabrication of fuel.

Capacity of the pilot plant will be 15 kg/day thoria (ThO_2 with an admixture of 4% UO_2). Outside dimensions of the complete plant are 150 × 75 ft. At its heart is a 35 × 15 ft hot cell for dissolution, feed preparation and solvent extraction processing of the spent elements. A key feature of the plant is the method of mounting, operating and maintaining hot process equipment by a unique mechanical system of movable racks. Should a piece of equipment become inoperable, the rack holding it would be removed to a decontamination and repair cell.

ACRS Suspends Judgment on Peach Bottom, Raises Questions on Safety; Approves NS Savannah Startup

Two important decisions taken by the Advisory Committee on Reactor Safeguards in mid-December were the last before the SL-1 accident in Idaho cast its shadow over the entire already-vexing question of reactor safety regulations and site criteria. On one case—NS *Savannah*—ACRS hoisted a green light; in the other—Peach Bottom—a yellow caution signal was raised.

Peach Bottom

A cautious, conservative position taken by ACRS on the Peach Bottom, Pa, reactor saw a number of questions raised about the design of the 40-Mwe High Temperature Gas-cooled Reactor being developed by General Atomic division, General Dynamics, for Philadelphia Electric Co. and 51 associated utilities. The reactor is to use combined fuel-moderator elements containing enriched uranium and thorium carbide in graphite cladding. Bechtel Corp. is architect-constructor for the $52.8-million project ($14.5-million of that cost being AEC research-development aid, plus $2.5-million in fuel use-charge waiver).

"The Committee continues to be optimistic," said the ACRS in its report to AEC Chairman McCone, "that a reactor of the general type proposed in the advanced gas-cooled concept can be constructed and operated at the Peach Bottom site without undue risk to the health and safety of the public. General Atomic has embarked on an extensive research and development program related to this reactor. The initial results from this program appear to be favorable.

"However, there are many questions that remain to be answered by the research and development program which is still in its early stages. Several of these questions are in areas which could require major changes in the present design concepts and could conceivably change our early optimism. For example, the long-term integrity of the graphite under the proposed design conditions, which lie far outside past experience with graphite, has yet to be established. Also, the experimental data required to determine that the fission products emitted continuously from the homogeneous fuel components can be collected, stored and disposed of safely have yet to be developed. A novel design is proposed for the control rod system, but the development is not yet sufficiently advanced to permit adequate evaluation of its reliability. The applicant has not provided either a secondary back-up safety system or an emergency coolant system, nor has it yet established to the satisfaction of the Committee that these systems are unnecessary. The relatively large assumed Doppler coefficient has yet to be confirmed.

"In view of the foregoing, ACRS is not now prepared to go beyond its original conclusion reached in our letter to you of March 14, 1960, that the Peach Bottom site is suitable for a reactor of this general design and power level."

Meantime the construction permit Philadelphia Electric requested July 25, 1960, remains on AEC's list of pending licensing business. With construction start already six months behind the date set in the proposal made to AEC by the 52 utilities, General Atomic is faced "not only with the reactor's development—but its invention," as one AEC staff member puts it.

NS Savannah

ACRS' action on the world's first nuclear merchant ship, although basically more positive, also contained reservations, namely two restrictions.

Subject to these restrictions, ACRS concluded that "the reactor can be operated without undue hazard to the health and safety of the public" through its period of sea trials. The restrictions are: 1. that the reactor not be operated at more than 7 Mwth—10% of full power—at dockside at Camden, N. J., where she is being built; and 2. that before she goes into experimental service at sea, her performance "be documented for formal review by the AEC staff and ACRS . . . to establish as soon as possible what limitations, if any, should be placed" for safety reasons on operation of the ship.

ACRS also recommended: 1. review of the results of the startup test program through the 10% power level before the reactor is taken to higher power levels; 2. a study of the chance that flooding of the reactor compartment as a "last resort" protective procedure might have undesirable consequences, in particular adverse stresses induced by possible contact of cold water with the hot containment vessel; 3. review of the program to develop a nondestructive monitoring procedure for frequent checking of the filters for iodine and particulates; and 4. review of the pertinence of recent failures of 17-4-PH steel to be used in *Savannah's* control rod design. On the last point, a high official of the Maritime Reactors Branch told NUCLEONICS that all 17-4-PH steel used in *Savannah's* control rod drives is of the 1100° F heat-treated variety (see story on Dresden rod drives, p. 25) and therefore not subject to the stress corrosion cracking that occurred in Dresden parts made of 900°-treated steel.

Seaborg nominated to AEC chairmanship

An eminent scientist-administrator, California University's Glenn T. Seaborg, was nominated for the AEC chairmanship last month by President John F. Kennedy. Seaborg would be the first scientist ever to lead the nation's nuclear program. On his nomination, he was chancellor of the University of California at Berkeley and associate director of the Lawrence Radiation Laboratory.

The 48-year-old chemist was born Apr. 19, 1912, at Ishpeming, Mich., took his bachelor's degree at the University of California at Los Angeles in 1934 and his doctorate at Berkeley in 1937. Included in his nuclear background are major contributions to the identification of plutonium and uranium-233 and the discovery of nine new transuranic elements—94 through 102. Under Seaborg's leadership, particularly in the field of heavy elements, whole bodies of methodology and instrumentation have been pioneered. Seaborg won the Nobel Prize in chemistry in 1951.

Industry's reaction appeared to be compounded of neutrality and high hopes, of familiarity with his fine scientific reputation and unfamiliarity with his personality. Most industry spokesmen expressed a "watch and wait" attitude; those who knew him were high in their praise. His views are relatively little known; in a 1958 speech he looked forward to competitive nuclear power being "within reach in a few years." A registered Democrat, he brings AEC's political make-up to 2-and-2, and nomination of the fifth commissioner was expected soon.

REACTOR NEWS

ORNL TO BUILD FAST BURST REACTOR

The $1.4-million Fast Burst Reactor, small enough to be suspended from a balloon if necessary, will be built at Oak Ridge National Laboratory starting in April. FBR will provide short bursts of radiation—40 microsecond bursts of fast neutrons as free as possible of thermal neutrons, 10^{17} fissions per burst—for biomedical and health-physics research. The core will consist mainly of uranium-molybdenum alloy, without moderator or shielding. Power levels will range up to 1 kwth. FBR will be suspended on a derrick at new facilities ~2 mi from the Tower Shielding Facility and behind a ridge. The program includes the possibility of taking the reactor to the Nevada test site where instead of the derrick, a balloon would hang FBR over various experiments. Included in FBR's work schedule are instrument development and dose studies, medical uses of radiation, solid state physics, nuclear chemistry, and neutron physics research. NDA will build and install the reactor.

PG&E APPROACHING DECISION ON 300-Mw UNIT

Pacific Gas & Electric Co. has been aiming at making its decision by Feb. 15 on whether to build a 300-Mwe-plus power reactor, probably at Bodega Head 50 mi north of San Francisco. If built, the reactor would probably be a General Electric boiling water reactor. PG&E engineers analyzing what the economics of GE's proposed plant would be on their system, are approaching the end of their studies: if these show 6.5 mills/kwh power cost to be attainable, the utility will go ahead. Most recent reports from PG&E, however, indicate that the situation is still far from being cut-and-dried: that the Feb. 15 date may not be met, and that "a lot of pencil-sharpening" is underway. Meanwhile at PG&E's Humboldt Bay station work is proceeding on sinking a caisson into the ground for the 50–75-Mwe reactor and its surrounding pressure-suppression chamber. The Humboldt Bay reactor—Unit No. 3 at an already existing conventional station—is expected to make power at 8–8.5 mills/kwh from its second core. Completion of construction at Humboldt is still scheduled for March 1962, despite the delays in granting of the construction permit. This would mean initial criticality in June 1962; PG&E's power department wants to be able to draw firm power by fall of 1962.

PARSONS, THIOKOL WIN ROCKET FACILITY

Chosen contractors for the coveted job of designing the new National Nuclear Rocket Development Facility in Nevada (NU, Dec. '60, 27) were the team of Ralph M. Parsons and Thiokol Chemical Corp. The contract, when finally negotiated, will cover a four-month architect-engineering design study. It will also consider detailed site data, number and type of test stands needed, control center, support facilities, assembly and disassembly buildings, water and electricity needs, and construction costs and schedules. The facility is expected to be a huge one costing many millions. Unofficial estimates put the amount of the contract at $150,000–200,000. Other finalists in the bidding—from 12 original proposers—were Bechtel Corp., and Aetron division of Aerojet-General Corp. Thiokol, nuclear subcontractor to Parsons, is part of a four-company team known informally as TALANT and including Allison division of General Motors, Linde Co. division of Union Carbide, and Nuclear Development Corp. of America.

ELK RIVER STARTUP DELAYED

Fuel element problems have delayed initial criticality of the 15-Mwe Elk River boiling water reactor, near completion by Allis-Chalmers for Rural Cooperative Power Assn. Martin Co., fabricator of the elements, is expected to take back all the 87 it delivered, after weld overheating was discovered to have caused leaks in outer tube walls. Project officials however said the delay was not unwelcome, because of their extremely tight schedule to go to power. AEC had scheduled a hearing late last year to authorize Elk River to go to power 90 days after authorization, but has now postponed the hearing to March 7. Preoperational testing of the 22-Mwe facility (with 7 Mw coal-fired superheater) is still going on. Under the new schedule, core loading is to take place shortly after the March hearing, with full power to follow in 90 days.

PM-2A GETTING MORE SHIELDING

The PM-2A reactor at Camp Century under the Greenland icecap was shut down in late November before completing its acceptance tests when localized neutron streaming was discovered in a 30° cone above the reactor. This would have affected only the plant's prescribed ability while at full power to unload previously-spent fuel elements from the spent fuel tank above the reactor (designed to provide shielding above the core as well as decay cooling for spent fuel). Nevertheless Alco Products, the reactor's builder, designed additional shielding which has been shipped up to the site and is now being installed. Resumption of operation was expected in late January. Prior to shutdown the plant had carried the entire Camp Century load (700 kw, about half the reactor's 1.5-Mwe capacity) for three periods of 6–10 hours.

CORNING OUT OF SYLCOR

Sylcor became a wholly-owned division of Sylvania Electric Products Inc. on Jan. 1, Corning Glass Co. having completely retired its remaining interest in Sylcor—originally a 50-50 joint subsidiary. Corning last spring had sold to Sylvania "a substantial portion" of its 50% holding. Despite Corning's withdrawal, the joint name Sylcor (from Sylvania-Corning Nuclear Co.) will be retained; the unit will be known as the Sylcor division of Sylvania Electric. Lee Davenport, formerly president of Sylvania-Corning Nuclear, is now general manager of Sylcor division and a vice-president of Sylvania Electric.

GE REPLACING DRESDEN, RWE CONTROL PARTS

The 15-Mwe RWE reactor at Kahl, Germany, is now shut down in the wake of the Dresden shutdown (NU, Jan. '61, 25), to get the same modification: replacement of control-rod-drive components made of 17-4-PH steel heat-treated at 900° instead of 1100° F. The new Armco steel alloy (17% chrome, 4% nickel, precipitation hardened) had been chosen for its hardness, for the tubes connecting the control rod drives to their control blades; it develops that the 1100°-treated variety, not entirely as hard as the 900°-treated steel, is in a less brittle condition, can take more impact shock and does not develop the hairline cracks that appear in the latter under tensile load in hot water, apparently because of residual stress remaining after die drawing. In other parts of the control rod drive system where wear resistance is not vital, the 17-4-PH steel is being replaced by austenitic stainless steels of the 300 series and by inconel-X. GE now hopes to get Dresden back on the line by not later than May 1, Kahl in February or as soon as the German Federal government issues a license.

WORLD NEWS

Britain Plans Biggest A-Station

The world's largest power station, 800 Mwe, has been proposed by Britain's Central Electricity Generating Board. CEGB has applied to the Ministry of Power for a site near Wylfa Head, facing the Irish Sea on the north coast of Anglesey island, northwest Wales. If the Ministry grants permission, Wylfa Head will be the ninth civil nuclear power station in Britain (six are under construction; the contract for No. 7, Sizewell, was awarded late last year (NU Wk, 1 Dec. '60, 5); and a contract for No. 8, Oldbury, is expected to be awarded shortly). Together the nine stations total just under 4,500 Mwe, all of which should be available by 1967. CEGB's goal is 5,000–6,000 Mwe by 1968. There is as yet no indication whether magnox-clad fuel elements (as in Calder and the first seven or eight civil station) will be used, or whether the Advanced Gas-cooled Reactor concept, next stage in British development of gas reactors, is planned. Following extension of the British nuclear program's time scale, there is some evidence that the degree of urgency associated with the AGR program and the 30-Mwe AGR prototype at Windscale have been relaxed.

Owen Raps British Steel Makers

The British steel industry was harshly criticized by Sir Leonard Owen, member of the U. K. Atomic Energy Authority, for not having sophisticated steels for use in the British nuclear program. Addressing a symposium on steels for reactor pressure circuits, he cited two major examples: the metallurgical problems in building the diffusion plant at Capenhurst, and the enforced use of low carbon steel that results in low-tensile-strength steel for reactor vessels.

Bechtel Designs Power Reactor for Spain

A preliminary design of Spain's projected first nuclear power plant has been completed by the Bechtel Corp. The reactor is the 30-Mwe dual-purpose power-and-test unit, heavy water moderated and organic cooled, that Atomics International proposed in a design competition in 1959. AI would supply the reactor, and Bechtel was engaged by Spain's Junta de Energia Nuclear to make a preliminary design of the over-all plant, including cost estimates and time schedules. The Junta was reported as being confident that construction on the project would begin this year.

France's EDF Plans 4th Reactor

Electricité de France is planning a fourth large reactor in its series of gas-cooled graphite natural-U power reactors. Several sites in Normandy are already under study for EDF-4 (EDF-3 will be the last reactor built at the Chinon site because of limitations on cooling water available from the Loire). EDF-4 is presently expected to be an optimized version of the CO_2-cooled EDF-3, and to have a net output in the range of 450-Mwe, and two 250-Mw turbines. A fourth generation commercial plant, EDF-4 should not, incidentally, be confused with EL-4, the 80–100-Mwe reactor in the Monts d'Arrée region of Brittany (NU, May '60, 28), which will be heavy-water moderated—although also natural-U fueled and CO_2-cooled—and will be built as an experimental plant by the Commissariat à l'Energie Atomique.

U. S. May Join ENEA Under New OECD

The U. S. may become a full member of ENEA—the European Nuclear Energy Agency—in the wake of replacement of its parent organization, OEEC (Organization for European Economic Cooperation), by a new body of broader aims and scope, the Organization for Economic Cooperation and Development. Signature of the treaty setting up OECD by the U. S. last month marked the U. S.' intention of joining OECD as a full member after having participated in the work of OEEC for some 12 years as only an observer, then as associate member. ENEA will remain essentially unchanged, continuing as a semi-autonomous agency under the aegis of OECD. The U. S. and Canada—both of which had been associate members in OEEC and will become full members of OECD—will be free to decide whether or not they wish to increase their degree of involvement in ENEA from associate to full membership. ENEA, which now numbers 18 full members—all European countries—frankly hopes the U. S. will choose to become a full member. As for Canada, associate membership has worked out so well that it is "perfectly satisfied with the way things are now."

ENEA Sets Up A-Ship Study Group

A study group on nuclear ship propulsion has been set up by the European Nuclear Energy Agency. The group has been assigned to make a broad study whose scope will include the pros and cons of nuclear propulsion for merchant ships; the type of reactor (and whether current or more advanced design) and what type of ship (category and size) would be best suited to a first venture; the feasibility of designing, building and operating a nuclear ship as a cooperative international project; and the best approaches to such problems as third-party liability, public health, and operating regulations and procedures.

Israel to Build 24-Mwth Reactor

Israel's project for a pilot power reactor calls for a 24-Mwth natural-U fueled, heavy water moderated, gas cooled reactor, according to Prime Minister David Ben Gurion's address to the Knesset (Parliament) Dec. 21. The unit will be of Israeli design, with French participation on supply of parts and materials, including electronic control equipment. The project—although "dedicated entirely to peaceful purposes," in Ben Gurion's words—had previously been kept secret 18 months allegedly for fear of repercussions among the Arab states. When word got out, a week of wild rumors and speculation followed culminating in diplomatic inquiries to assure that Israel was not planning a plutonium production reactor for a weapons project. The reactor is to be built in the Negev desert south of Beersheba, where Israel has uranium-bearing phosphate deposits for which it has been working for years to develop an economic extraction process. Ben Gurion said the purpose of the reactor—which will not have power-conversion equipment—will be for extension of atomic research in science, medicine, agriculture, etc., and for accumulation of experience looking to later construction of a power reactor. The project, under way over a year, is to be completed in 3–4 more years.

SENN Planning 2nd Reactor

A second power reactor, adjacent to the 150–225-Mwe General Electric boiling water unit now under construction between Rome and Naples, will be started by SENN in 1962, according to authoritative sources in Italy. Details on the second unit were not available, but U. S. observers said there was plenty of room and cooling capacity at the site.

NEWS IN BRIEF

Radiation Institute Organizes; Objectives Stated

The idea of establishing an Institute on Radiation, first conceived last May, has taken roots. An informal working group dug in at Chicago recently, drafted a statement of proposed objectives, and set out to answer basic questions of organization: status and funding. This group declared its primary objective was: to help the public gain understanding on the meaning and effects of radiation by creating an institution to which the public could turn with complete confidence for radiation information. Still unanswered is the question of status: the group sought to decide whether to organize independently, or attempt to affiliate with a university. On funding the institution, the group sought answers to long-range financial commitments required to support the organization. They did, however, establish the institution's needs for a period of several years at $500,000—$1-million; they will ask for grants from foundations interested in supporting such a program. Working papers used during preliminary talks emphasize essentials the group feels imperative to the success of the organization: "The institute must be free from any semblance of subordination to any group identified in the public mind with special interests"; and "in order to attain practical acceptance among those working in the field, the institute must maintain an intimate working relationship with all groups." Those active in the working group include: F. Aley Allan, Mobil International Oil Co.; Joe W. Howland, Univ. of Rochester; Charles F. MacGowan, Int'l. Brotherhood of Boilermakers; John H. Rust, Univ. of Chicago; Elwood Swisher, Oil, Chemical and Atomic Workers; G. Edwin Brown, AIF; William A. McAdams, General Electric; C. Rogers McCullough, Nuclear Utilities Service Co.; and Bernard B. Smyth, Dow, Lohnes, & Albertson, Washington, D. C., law firm.

AEC Sets Up New Coordination Office

AEC grants for nuclear equipment and other types of training assistance in nuclear technology will now be administered from one office. This new coordination office is established within that of the Assistant General Manager for Research and Industrial Development under Alfonso Tammaro. John C. Cera, previously chief of education and training for the Reactor Development Div., will be the first coordinator, reporting directly to Tammaro. Under Cera's single management will fall AEC grants—domestic, not foreign—for purchases of nuclear equipment; loans of source, by-product and special nuclear materials; special AEC fellowships in nuclear science and engineering, health physics and industrial hygiene; training for prospective nuclear power station operators, and facility training for high school and college teachers in handling radioisotopes.

When AEC announced last August it would discontinue training reactor grants, a major reason was removed for having the Reactor Development Div. handle the training grant program. Then, Cera's staff was transferred out of a single division to a higher level. (This move is one of many reflecting AEC's effort to consolidate assistance programs now scattered throughout the divisions of Reactor Development, Biology & Medicine, Research, and the Office of Isotope Development.) To replace training-reactor assistance, AEC plans to provide less-expensive subcritical assemblies and reactor simulators. However, for existing university research reactors AEC will still provide fuel loans, start-up sources, fuel fabrication and reprocessing services. The National Science Foundation will continue to assume primary Federal responsibility for giving construction aid for such reactors.

NUMEC Gets AEC Operating License

Nuclear Materials and Equipment Corp. has been granted an operating license for its plutonium facility at Leechburg, Pa. Although the lab has been completed for months, all hazard questions had to be answered before AEC issued the license. Now NUMEC will use the facility primarily on a Pu-oxide fuel-cycle contract with AEC. In addition, it will fabricate Pu-beryllium neutron sources which are now available only from AEC's Mound Laboratory. AEC promises to channel all commercial inquiries for neutron sources to NUMEC. Battelle Memorial Institute, equipped to conduct studies on all aspects of Pu metallurgy, has the only other privately-owned Pu lab in the country.

AEC Sets Up Access to Gas Centrifuge Knowledge

An access-permit program has been established by AEC for industry to use the now-secret gas centrifuge technology. To gain access to the information, AEC says, the firm "must demonstrate a capability for, and a serious interest in, making a substantial effort to engage in gas centrifuge development." Also, industry representatives must gain AEC security clearance and agree to comply with other requirements.

AEC Requests $2.68-Billion for '62 Spending

The so-called McCone Commission last month submitted its last budget—asking Congress to include a budget of $2.68-billion for the fiscal year beginning July 1, some $20-million less than estimated current spending. Chairman John A. McCone was to leave the chairmanship after 2½ years in the post. The $2.68-billion figure included $2.505-billion for operating expenses and $175-million for new capital spending; traditionally, the latter construction figure is low when the budget is first submitted and is increased as AEC goes through its construction-authorization process in Congress. For example, AEC said it would request supplemental funds for the $130-million Stanford linear accelerator if it is authorized later this year. Some highlights of the 1962 budget:

1. The overall increase of $20-million from current spending does not reflect increased spending for civilian development programs; actually there is an increase of $60-million for the weapons program, with the civilian total about $40-million less.

2. Operating funds for reactor development, as proposed, are down to $422-million from $438-million in the current year. This includes an extremely sharp cut in the Aircraft Nuclear Program—down to $33-million from this year's $72.6-million—reflecting an Administration decision to drop one of the two approaches now under investigation. Explaining this decision, President Eisenhower said simply, "The efforts to develop a nuclear engine for military aircraft will be continued in 1962 on one technical approach."

3. For the Office of Isotope Development, $5.5-million was proposed (another $570,000 was asked for isotope education and training). The $5.5-million figure compares with $3.8-million this year.

Yankee: 2nd U. S. Reactor to Reach Full Power

Yankee Atomic's pressurized-water reactor went to full licensed power of 110 Mwe on Jan. 17—the second large commercial reactor to do so in the U. S. Dresden was the first, reaching 180-Mwe last summer.

RADIATION NEWS

AEC's Isotopic Power For Space Under Way

A 4-part program on the safe use of isotopic power in space has been authorized by AEC. Martin Co. will manage the entire program. One of the four investigations planned is aimed at confirming theoretical burn-up data on re-entry of isotopic generators by firing simulated or actual cores into space. The other aims of the study program cover: 1. hazards of landing a radioisotopic generator on the moon (dispersion, length of contamination of different isotopes, etc.); 2. hazards of launching a generator from Cape Canaveral (all previous studies have been based on a West Coast launching—primarily Vandenberg AFB in California); and 3. development of a shielding code for isotopic generators (with a given isotope, what shielding is required? what is best shield shape, weight? how much radiation is self-absorbed?). Curium-242, polonium-210, cerium-144 and plutonium are the chief nuclides expected to be studied. They are considered the best sources for use in space since they require less shielding than, for example, strontium-90. Generators using strontium, cesium, and mixed fission products are expected to be used in terrestrial and marine applications, where shielding weight and size are not as crucial as in space. Martin and AEC having just begun negotiations, the extent of the space program is not yet defined; financial and other details are still to be worked out.

Low-Dose Irradiation of Potatoes Promising

A report received by the European Nuclear Energy Agency at a meeting in Paris in December showed low-dose irradiation of potatoes to be both economical and technically possible. Submitted by Conservatome, one of the sponsors of a food-irradiation facility near Lyon, France, the potato report was the first in a series on different foods ENEA plans to test under its low-dose food-irradiation program. Conservatome's reports created such interest that reports from representatives of four nations on work in their countries were contributed: eggs, being studied in Britain at Wantage; fruit juices, Austria; and two unspecified foods in Germany and Holland. The meeting resulted in a decision to hold sessions twice a year and to establish a health-and-safety group to study the wholesomeness aspects of food irradiation, and to establish standards for irradiation of foods. ENEA will be working with the Food and Agriculture Organization of the United Nations. The U. S. AEC, which is also running a low-dose irradiation program for the U. S., has offered ENEA its full cooperation, and will contribute substantially to its studies.

U. S. Program: Meanwhile, the U. S. Interdepartmental Committee on the Radiation Preservation of Food—which has coordinating responsibilities over all governent activities in food irradiation—scheduled a meeting early last month to get status reports on AEC's Civilian Food Irradiation Program, the Army's program and the smaller efforts of the Agriculture Dept., the Interior Dept.'s Bureau of Fisheries and other agencies.

100th Analyzer Sold by Intertechnique

Intertechnique, French maker of multi-channel analyzers for markets throughout Europe, reports the sale of its 100th analyzer. Intertechnique has been working since 1957 under a license from Radiation Instrument Development Laboratory (RIDL); its Nuclear div. also manufactures radiation and reactor instrumentation for markets principally in France. Sales of the division in 1960, according to Commercial Director Robert Cohen, were increased from $1.3-million in 1959 to $1.6-million. Recently the company introduced a multi-probe radiation detector with interchangeable heads (for alpha, beta, gamma, and neutron radiation, plus radon) and has nearly completed its first multi-dimensional analyzers for simultaneous analysis of nuclide spectra; several have already been ordered, but are not yet delivered.

Intertechnique anticipates a major market in the nuclear field for small, sophisticated computer equipment—automatically processing information developed by detector and counting instruments. Cohen, admitting his company did not have any specific development program for such computers, said: "This is something we might want to get into." His estimates of nuclear instrument sales in various European countries were: France, $7–8-million; Germany, $5-million; Sweden, $3-million; Belgium, $2.5-million; Italy, $1.5-million; Denmark, $500,-000; Yugoslavia, $500,000; and Norway, $200,000.

Full Operation of U. K.'s Cobalt-60 Irradiator

Britain's 150,000-curie irradiator at Wantage, west of London, is expected to go into full operation this month for the first time. It is fully committed to meet commercial irradiation needs. British companies, most of them marketing medical and pharmaceutical supplies such as catheters, syringes, etc., have booked all the irradiator's available time for nearly a year after it goes into full-scale production. Since its completion about a year ago, Wantage has been plagued by a number of problems—worst of them: compaction of its packages as they were pushed past the cobalt source by a ram (NU, Feb. '60, 100). Plywood packages have now been designed to carry the product past the source, through twin conveyor systems redesigned to take the wooden carriers. By mid-February, the plant will be operating on a 6-day schedule around the clock.

Bureau of Mines Plans Large Irradiator

Design and specifications for a Bureau of Mines irradiator, using 100,000 curies of cobalt-60, were recently completed by Internuclear Corp. The new facility, to be located at the Bureau's metallurgical research center, Albany, Ore., still has no construction schedule, still needs the necessary funds. Bureau officials are hoping, nevertheless, to get construction under way by June 30 if money can be skimmed from other Bureau projects. "If not this [fiscal] year," officials say, "we will start next year." The Albany irradiator, scheduled for research on metals, coal, petroleum, etc., would be a conventional hot cell. Storage of the source is in water beneath the cell. It is rated at 200,000 curies of cobalt-60, but the configuration of the source has not yet been decided. AEC will provide the cobalt.

Tritium Cleared for Non-licensed Use on Dials

AEC has issued its first licensing exemption for the use of a radionuclide on luminous watch and other dials. The exemption permits purchasers of watches and other timepieces using tritium to do so without getting a license from AEC. Those applying the tritium to dials, however, would be subject to fairly strict AEC control. At least two radiochemical manufacturers in the U. S. have indicated interest in marketing tritium for dial use —New England Nuclear Corp. and U. S. Radium. Under the exemption, not more than 25 millicuries may be applied per timepiece and manufacturers must present the timepiece for prelicensing inspection by AEC, to demonstrate that AEC's standards will be met. AEC is also reviewing other nuclides for such clearance.

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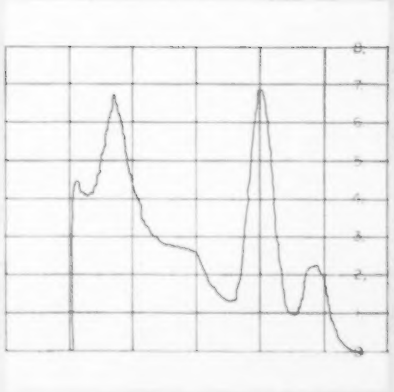

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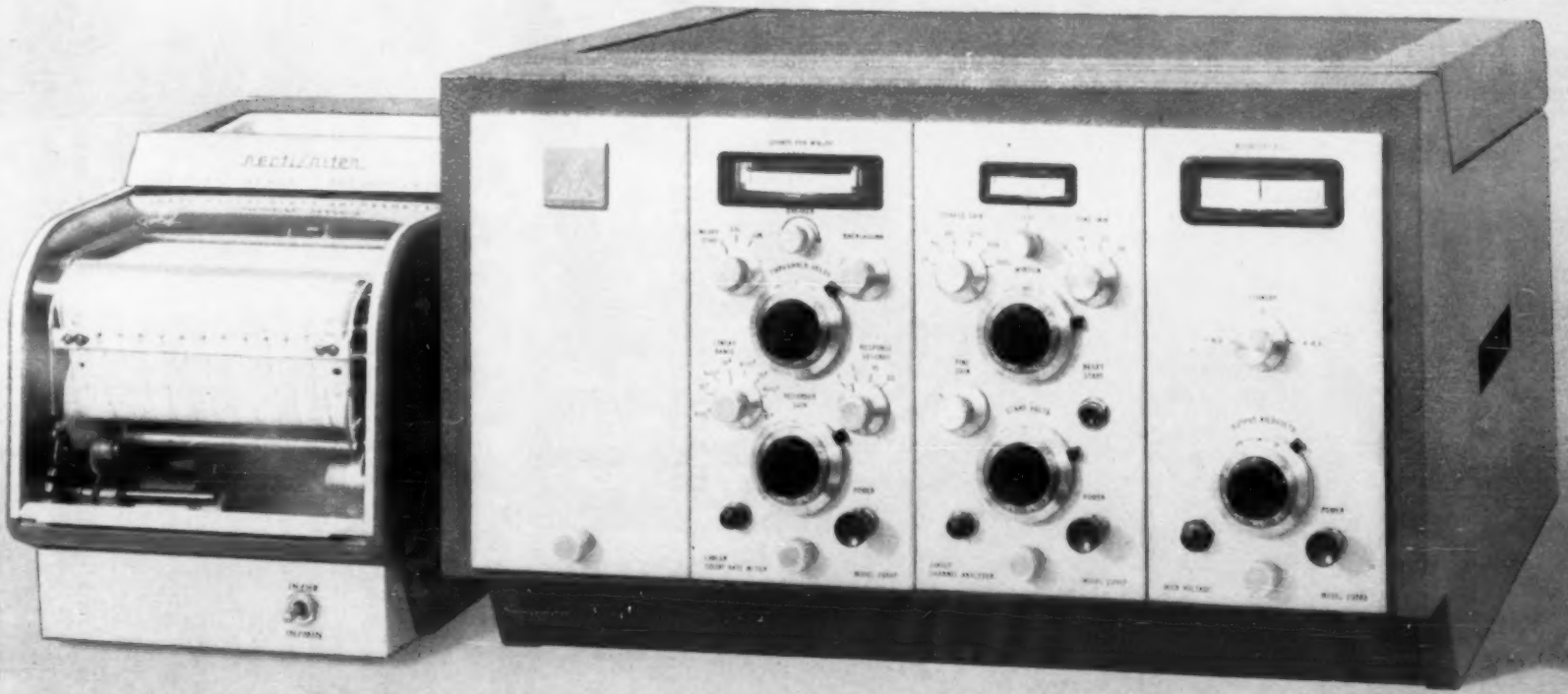

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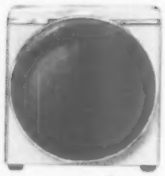

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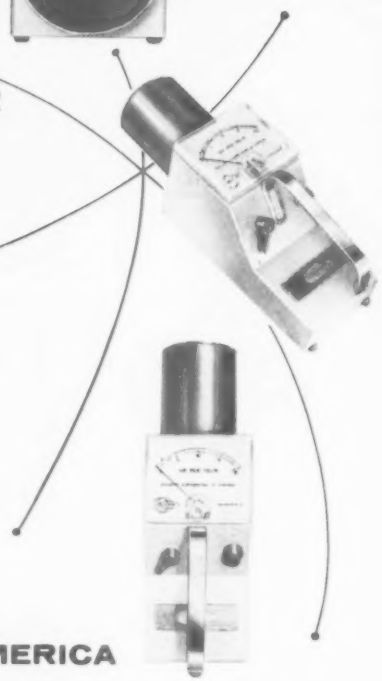

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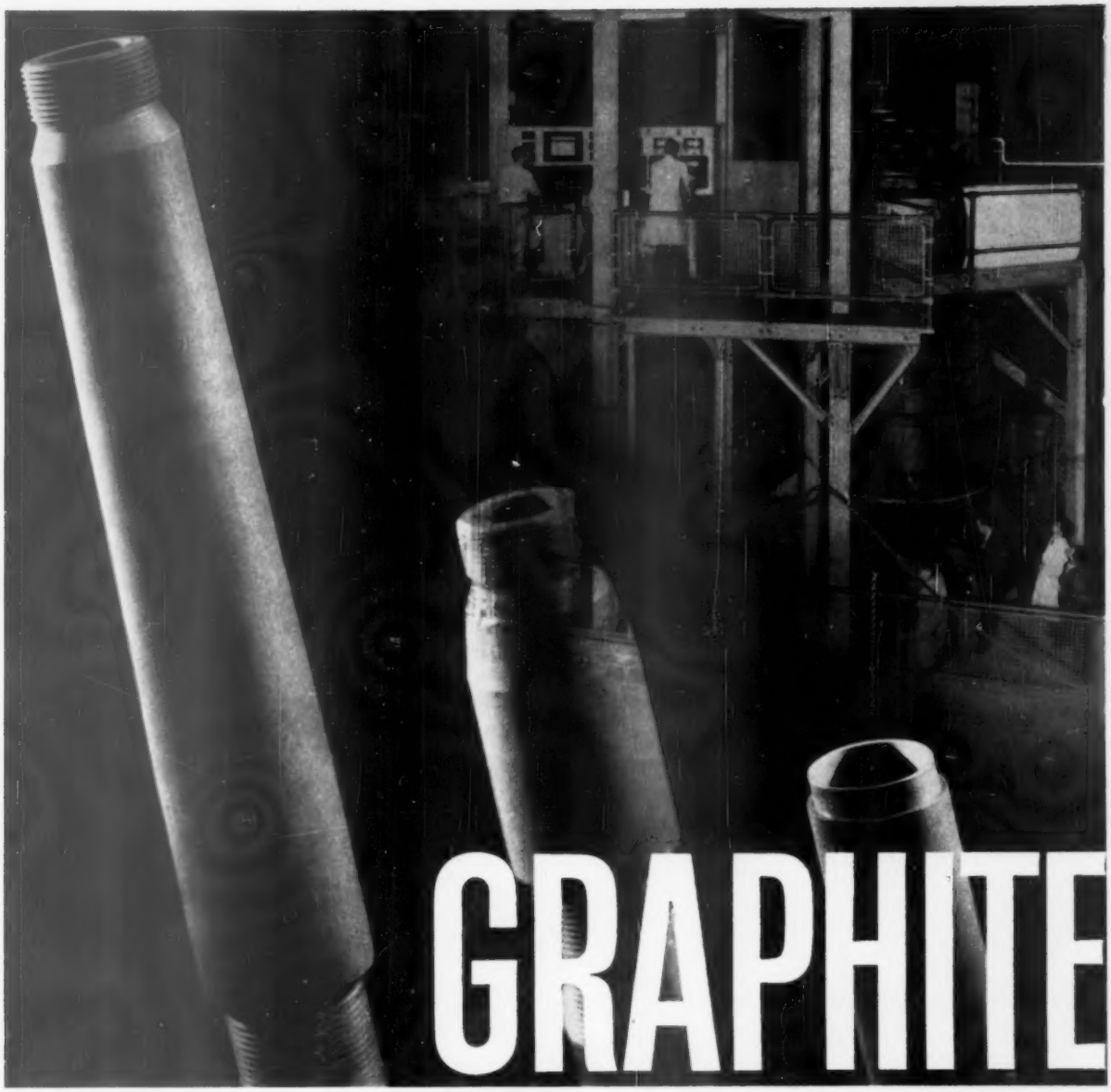

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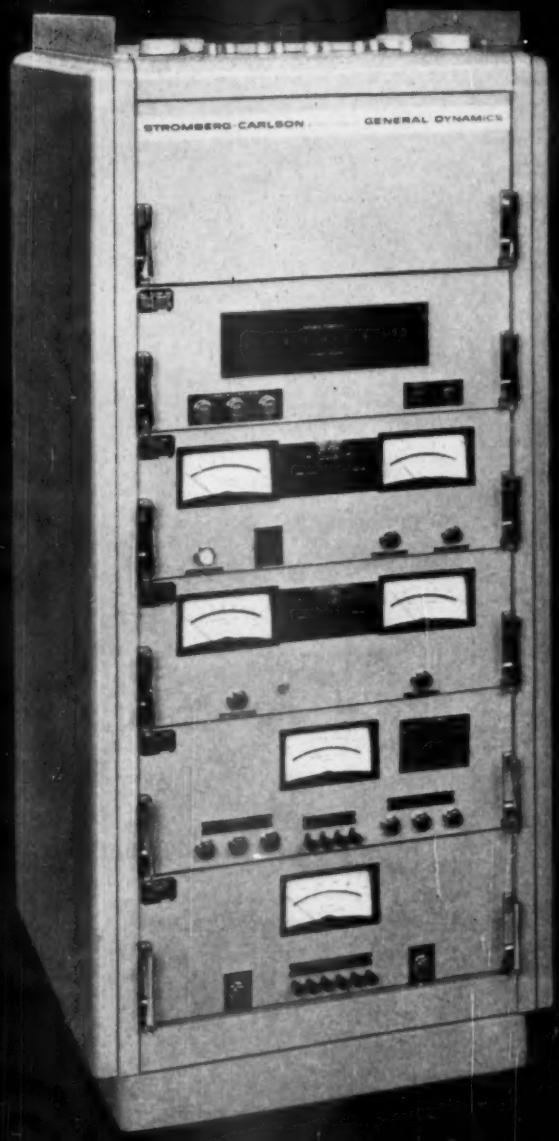

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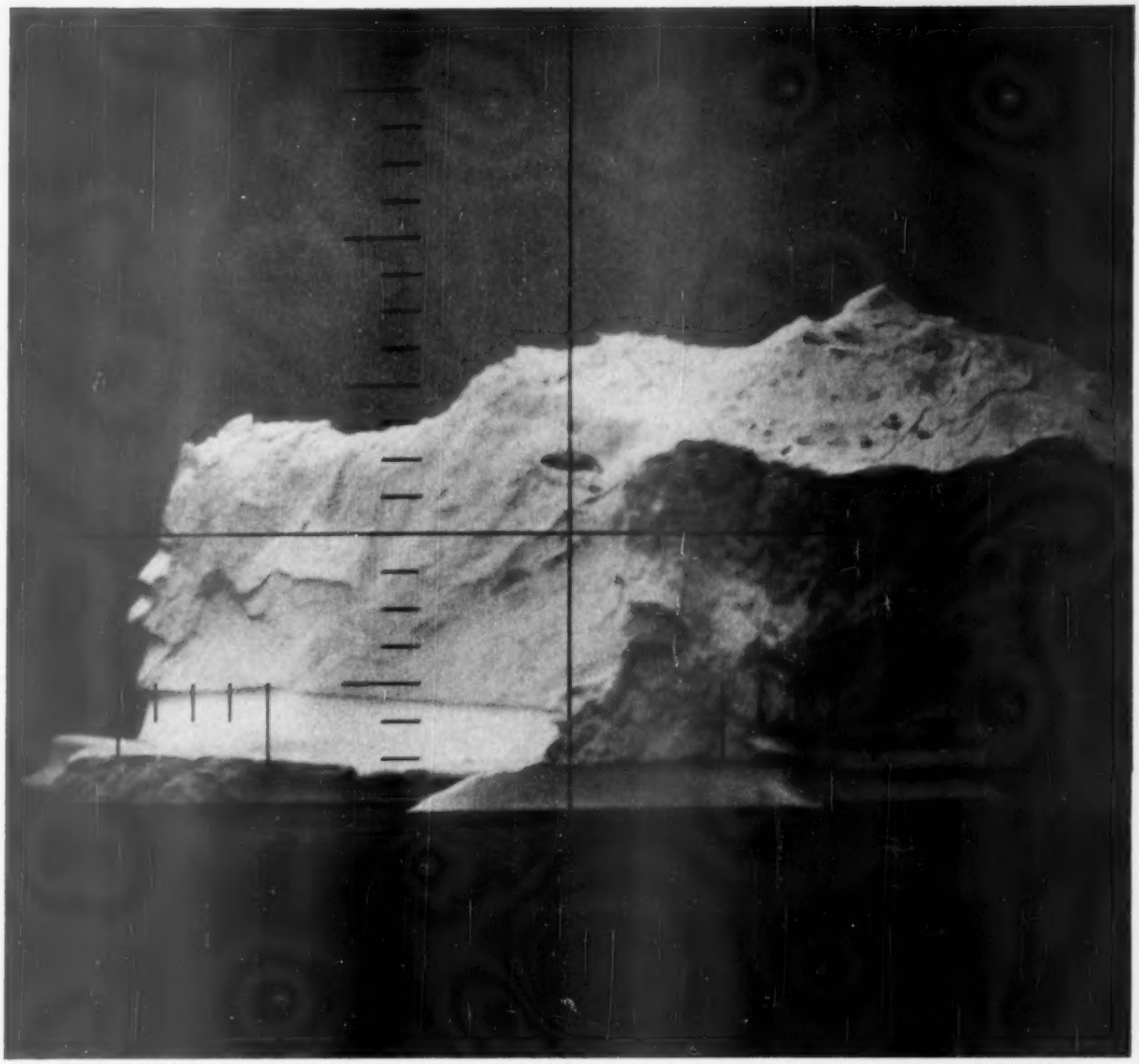

Official U. S. Navy photograph taken through the Kollmorgen 8B Periscope of the Seadragon during its polar cruise in August, 1960.

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Long, lonely reaches of the sea are prowled by our sentinel submarines . . . scanning the endless surface, listening and looking for signs of man. Kollmorgen periscopes, standard with the United States Navy including submarines of the atomic fleet, are highly sophisticated electro-optical systems delivering dependably clear viewing, photography and navigational data under the most severe conditions.

The talents and facilities which produce these periscopes are continuously developing many other products involving optics, mechanics and electronics. For instance, Kollmorgen hot cell and underwater periscopes permit remote viewing and photographing of radioactive material in nuclear installations. Continuous-strip cameras can now photograph the length of a moving track, entirely enclosed except for access as small as $\frac{1}{32}$".

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LEAD

Pb

NEW YORK, Feb.1 -- MORE THAN 25 MILLION POUNDS OF ASARCO CAST AND ROLLED LEAD HAVE BEEN USED FOR RADIATION SHIELDING IN PERMANENT AND MOBILE NUCLEAR REACTORS SINCE THE BEGINNING OF THE ATOMIC POWER ERA.

ASARCO

Asarco pioneered techniques that produce lead castings of such uniform high density that even gamma rays cannot find surface pinholes to penetrate. As a result, Asarco is a major fabricator of lead in the many forms required by radiological, chemical, refining, atomic, construction and other industries. Many of the mobile reactors in use today are shielded by Asarco patented interlocking lead bricks, and its lead sheet, plate and castings are found in permanent reactors, isotope packaging and atomic storage, shipping and disposal containers.

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For more detailed information about lead in all its forms and uses, write American Smelting and Refining Company, 120 Broadway, New York 5, N. Y.

Launching an atomic powered submarine with Asarco radiation shielding aboard. Inset shows method of anchoring the sub's lead shielding plates with Asarco lead wool.

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Now you can do ALL your sample counting

AUTOMATICALLY...with the New Tracerlab

multi/matic Sample Changer

The SC-101 Manual Flow Counter with ultra-thin Mono/mol Window Detector.

New FD Series Flow Counter with the ultra-thin Mono/mol Window features plug-in assembly.

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Only from Tracerlab — the world's largest and *first* manufacturer of Sample Changers could you expect — and get — such a revolutionary new system.

The New SC-100 MULTI/MATIC Sample Changer provides positive, accurate positioning of samples. Samples are readily accessible because they are loaded and driven on a horizontal plane (in contrast to tower or stack types). Automatic recycling of a single sample, automatic bypass of empty sample positions, automatic recycling to the starting position plus the ability to operate with all types of detectors are other features of this most versatile new Tracerlab development.

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The New Tracerlab SH-1 Shield operates with either the automatic changer or the SC-101 Manual Changer pictured. It accommodates both the 1″ and 2″ FD Series Flow Counters, windowless flow counters, P-20D Scintillation Detectors or standard GM detectors. Convenient handles make it easy to insert or remove from any changer, shield thickness of 2 inches of lead provides low reproducible backgrounds.

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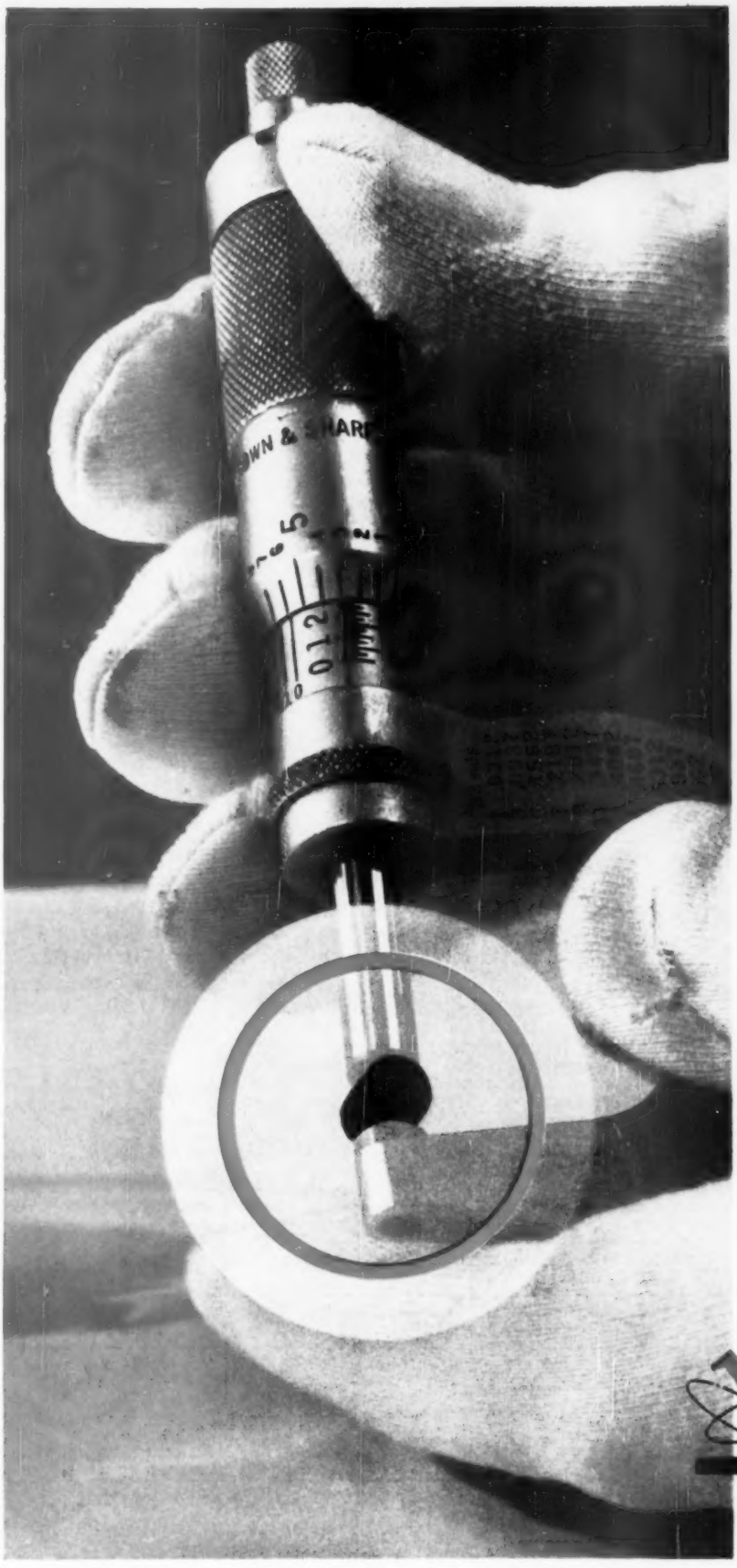

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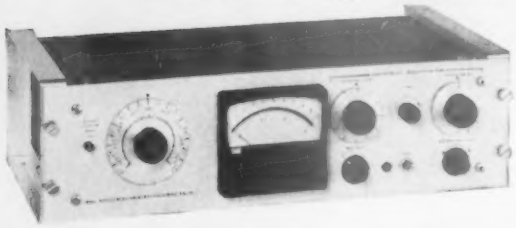
for nuclear instrumentation



The 415 provides zero suppression up to 100 full scales, current detection of approximately 1 x 10^{-14} ampere, zero stability of better than 2% per day.

Models 410 and 411 provide high sensitivity, low switching transients, high accuracy, fast response and low noise. Drive 5 ma recorders or 50 mv potentiometer types.

The log n circuit of the 420A has only three adjustments and the period circuit one adjustment. Period and current outputs unaffected by normal ambient changes.

NEW MODEL 415 research micro-microammeter has a response time of less than 600 milliseconds to 90% of final value at 10^{-12} ampere where external circuit capacity is 50 $\mu\mu$f. It is ideal for current measurements in ion chambers, ionization gages. Useful with flame and Beta-ray ionization detectors; in gas chromatography, mass spectrometry. **$750.00***

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MODEL	RANGE	ACCURACY	ZERO DRIFT	OUTPUT
410/410C†	10 x 10^{-4}, 3 x 10^{-4}, 10 x 10^{-5}, etc. to 3 x 10^{-13} amp f.s.	±2% f.s. on 10 x 10^{-4} to 10 x 10^{-9} ranges; within 4% on others.	After warmup, below 2% f.s. per 24 hours all ranges.	5 v f.s. up to 5 ma. Output noise below 1% of f.s.
411/411C†	10 x 10^{-4}, 3 x 10^{-4}, 10 x 10^{-5}, etc. to 10 x 10^{-12} amp f.s.	±2% f.s. on 10 x 10^{-4} to 10 x 10^{-8} ranges; within 4% on others.	Below 2% per week from cold start, input 10 v or more.	10 v f.s. up to 5 ma. Output noise below 1% of f.s.
412/413††	Single 10^{-7} to 10^{-13} amp, source voltage over 1 v.	Within 0.2 decade, with source voltage over 1 v.	Below 0.05 decade in 24 hours with source voltage over 1 v.	Zero at 10^{-13} amp to –6v at 10^{-7} amp; up to 5 ma.
414/414C†	17 ranges from 10^{-2} to 10^{-10} amp f.s.	Within 3% f.s. 10 ma to 10 mμa; 4% f.s. 3 mμa to 0.1 mμa.	2% per day with source voltage over 1 v.	5 v f.s. up to 1 ma. Output noise below 1% of f.s.
415	10^{-12}, 3 x 10^{-12}, 10^{-11} 3 x 10^{-11}, to 10^{-3} amp f.s.	±2% f.s. 10^{-3} thru 10^{-8} ranges; ±3% f.s. 3 x 10^{-9} thru 10^{-12}.	After warmup, below 2% f.s. per 24 hours all ranges.	1 v f.s. up to 5 ma. Noise below 20 mv rms.
420A Log n AMPLIFIER and PERIOD METER	Single, 10^{-6} to 10^{-13} amp, positive currents only.	Within 0.2 decade.	After warmup, below 0.05 decade in 24 hours.	High level—zero at 10^{-13} amp, –75 v at 10^{-6} amp. Recorder—50 mv f.s.
	Single, –30 to + three seconds.	3% at center scale.		High level — zero for 30 sec. period, 10 v for 3 sec. Recorder –50 mv f.s.

†Contact meter models have same specifications as standard units except for addition of a contact meter relay.
††413 same as 412 except: RANGE, 10^{-5} to 10^{-11} ampere.

KEITHLEY INSTRUMENTS, INC.
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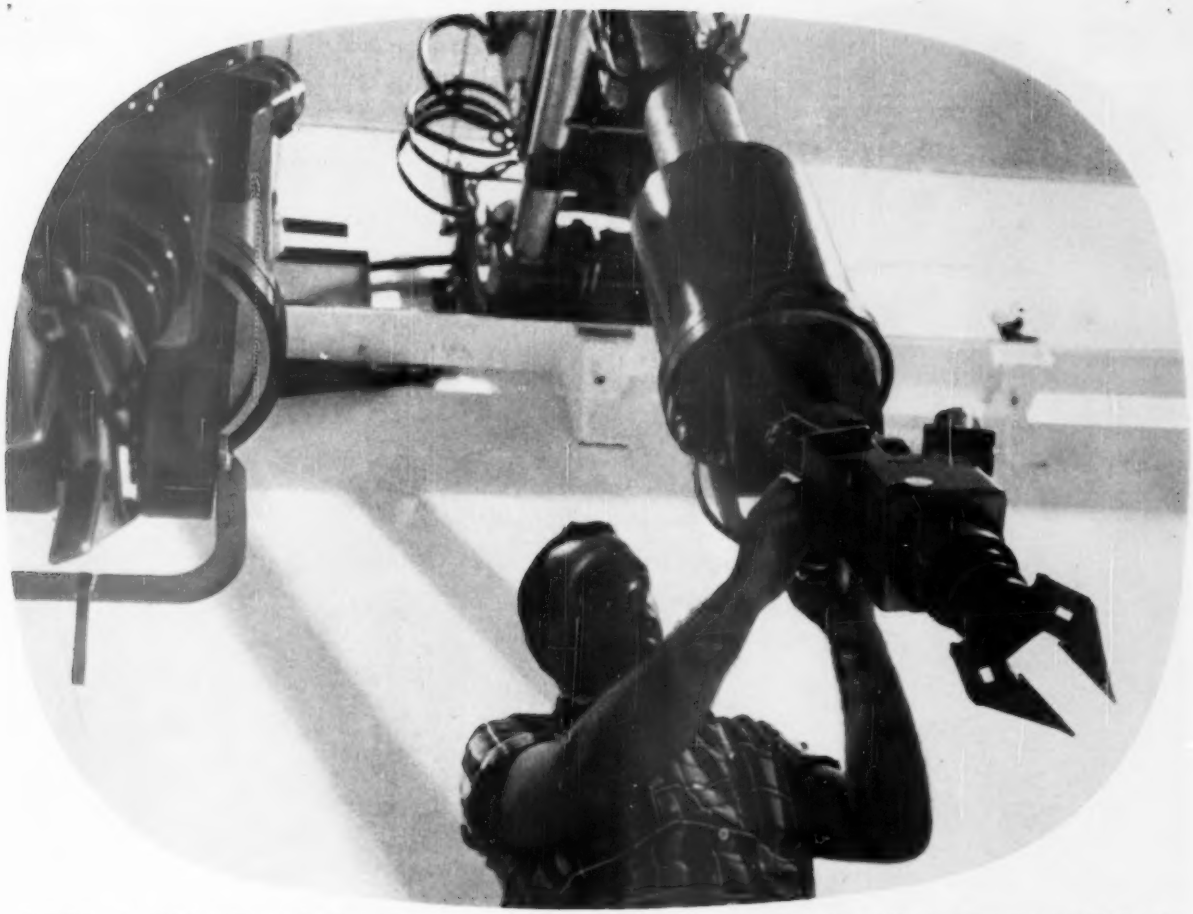


Installation completed, engineer makes final adjustment on General Mills Mechanical Arm.

Photo courtesy of Atomics International, a division of North American Aviation, Inc., Canoga Park, California.

At Atomics International these General Mills Mechanical Arms help solve remote handling problems

At Atomics International—as in most major atomic installations in America—General Mills Mechanical Arms lift great weights with ease, yet handle fragile materials with complete safety. During more than a decade of experience in the field, our Nuclear Equipment Department has built up a wealth of design know-how and engineering skill for solving remote handling problems.

You can best profit from this experience by consulting our engineers early in the design stage of your nuclear facility. With our planning services and full line of manipulating devices, chances are we can adapt one of our standard Mechanical Arms to meet your particular requirements, thereby saving you much custom design and engineering work.

SIX STANDARD MECHANICAL ARMS—All equipped with electric drives, variable speeds, finger tip controls and automatic connections for power tools.

MODEL 100—complete, low cost system ready for installation. Full cell coverage and 200 lbs. lift.

MODEL 150—Provides maximum manipulating versatility in a minimum of space. For example, alpha-gamma handling in a sealed dry-box.

MODEL 300—General purpose model designed for items from a few ounces to 750 lbs.

MODEL 500—A medium sized arm that handles loads up to 2000 lbs. with ease and dexterity.

MODEL 550—Gives great versatility on heavy load applications. Handles 100 lbs. cantilevered 18 ft. and proportionally higher loads as moment is reduced.

MODEL 700—The strongman of the line, equipped with a special hook mechanism for lifting up to 5000 lbs. loads.

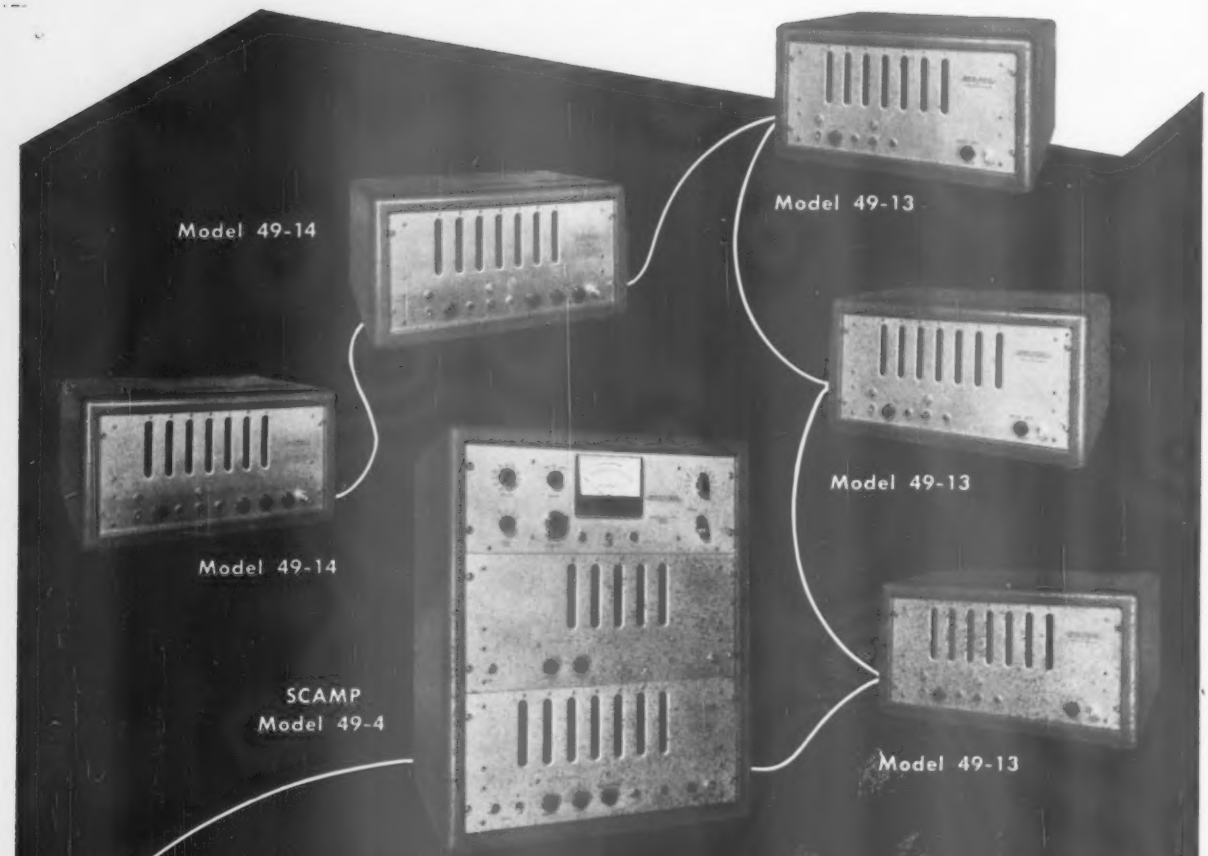
Write for engineering bulletins on all of these Mechanical Arms: *Nuclear Equipment Department, General Mills, Inc., 419 North Fifth Street, Minneapolis 1, Minnesota.*

NUCLEAR EQUIPMENT DEPARTMENT

General Mills

First in Remote Handling

MECHANICAL ARMS



All These Self-Programming Printing Scalers Connected to One Printer

(two to a dozen, or more)

FULLY AUTOMATIC OPERATION — Radiation Laboratory **automation** takes another step forward with RIDL self-programming **Printing Scalers.** Sequential data read out to any printer which accepts a 1-2-2'-4 four line binary coded decimal input makes possible the use of **any number of these printing scalers** with ONE printer.

The most popular **RIDL automatic scaling system** is the combination of the RIDL Model 49-4 SCAMP system with any number of Model 49-13 or 49-14 scalers, each connected to a different detector. Preset time, preset count, and fully automatic print out is thus available. Since these units are self-programming and adjustable for self-identification, they are interlocked — **without stepping relays and without special programming units** — for sequential read out if simultaneous printing times are reached. A tape punch may also be used to allow punched tape read out for data processing by computer methods.

The use of RIDL printing scalers increases research potential through providing continuous, completely automatic counting operation. RIDL offers the most complete line of scalers ever available. Whatever your scaler requirements may be RIDL has a unit to fill these needs. For further information write today to Department WM8.

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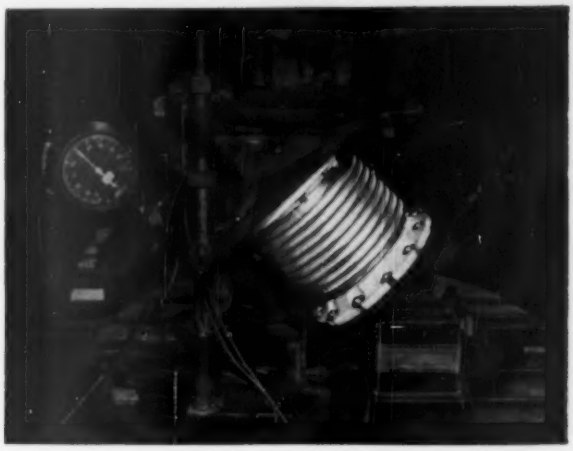
4 WAYS to get maximum reliability in expansion joints

1 Insist that the corrugated bellows be hydraulically formed. The reason is simple. Whenever bellows are formed by circumferential welding . . . whether by edge, seam or fillet welding . . . they will always be subject to premature failure because of stress concentrations at the welds.



2 Be sure the manufacturer maintains a continuous and comprehensive program of endurance testing. This is basic, because of the many variables that affect expansion joint life. Accurate determination of expansion joint life expectancy can only be determined by cycling to destruction.

3 Demand proof that the manufacturer can produce longitudinal welds in the corrugated bellows having the same strength, physical properties and thickness as the parent metal . . . without grinding. A weld that is hard to find is a ground weld. Variations in weld thickness set up points of stress concentration . . . opening the way for premature failure.

4 Check the ability of the manufacturer to supply a team of *competent* design and application specialists to work with your engineers. Check their specific experience in handling critical, complex applications in your field . . . complete to the record of successes or failures behind them, and details of how this experience will be brought to bear on your problem.

At Zallea, none of the many factors affecting expansion joint reliability are left to guesswork . . . including the four vital ones above.

This is reflected in these facts. Zallea material specifications are the most exacting in the industry. Zallea expansion joints are hydraulically formed. Zallea advanced welding techniques insure welds having the same thickness, strength and physical properties as the parent metal. Zallea has done more cyclic testing to destruction than all government agencies and industrial firms combined. Zallea has produced more expansion joints than any other manufacturer . . . offers more application engineering experience.

For all the facts, write for Catalog 56. Zallea Brothers, Taylor and Locust Streets, Wilmington 99, Delaware.

Zallea for maximum reliability

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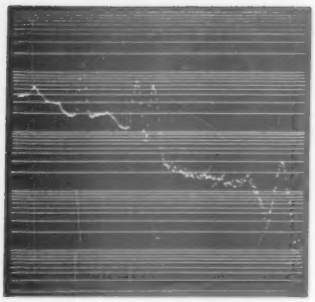

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ANNOUNCING THE NEW NUCLEAR DATA 512 CHANNEL ANALYZER,

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Model ND 120: Based on the highly successful Nuclear Data Model ND 102 analyzer but with

- 512 CHANNELS
- LIVE DISPLAY
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- ONE MILLION COUNT CAPACITY PER CHANNEL

This analyzer uses an excellent new analog-to-digital converter, which provides the finest linearity, stability, freedom from count-scatter, and most precise live time determination available at any cost.

Except for minor circuit and specification changes, the design of this analyzer is the same as for the thoroughly proven Model ND 102. Analyzer includes all typewriter control and drive circuits.

One of the problems encountered in offering a fine analyzer, moderately priced, results from the natural tendency of people to assume (in the absence of complete evidence) that higher price implies higher quality. We do not believe that an artificially high price is the correct long range solution to the problem. We can only point out that this is a considerably improved version of the Model ND 102 analyzer, which is probably the most dependable analyzer previously produced. We can point out that the analog-to-digital converter has, after comparative tests, been selected for use in compiling a new catalog of gamma spectra, which obviously requires the finest linearity, freedom from count scattering, timing precision, and wide range of energy coverage. The authors of two previously compiled gamma spectrum catalogs are now owners of Nuclear Data analyzers.

The new Nuclear Data analyzers utilize the finest quality components, including the rugged, fast, mesa transistor (for all scaler and register stages). Imaginative circuit and production engineering, including simplified logical design, has resulted in a new analyzer which is dependable, easy to use, exceedingly precise, and yet moderate in price.
Write for full specifications.

256 CHANNEL MODEL ND 102 PRICE $9,400
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NUCLEAR DATA INC., 3833 WEST BELTLINE, MADISON, WISCONSIN

New Step Toward Economic Nuclear Power

A broad program aimed at important reductions in the cost of nuclear electric power has been initiated by the Empire State Atomic Development Associates, Inc. (ESADA). This group of seven New York electric utility companies has selected General Dynamics' High Temperature Gas-Cooled Reactor (HTGR) for intensive research and development as part of their program directed toward the construction of a large nuclear power plant in New York State competitive with conventional-type plants.

Under this program, General Atomic Division of General Dynamics will carry out research and development in extending its HTGR system to a large-scale plant of 300,000 to 500,000 kilowatts electrical capacity, which would be capable of producing the high steam temperatures and pressures required for the use of modern steam turbines.

The member companies of ESADA are:

NIAGARA MOHAWK POWER CORPORATION
LONG ISLAND LIGHTING COMPANY
NEW YORK STATE ELECTRIC & GAS CORPORATION
CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
ROCHESTER GAS AND ELECTRIC CORPORATION
CENTRAL HUDSON GAS AND ELECTRIC CORPORATION
ORANGE & ROCKLAND UTILITIES, INC.

Selection of the HTGR for the ESADA program is based on progress in the development of the prototype 40,000 kilowatt HTGR plant, being built at Peach Bottom, Pennsylvania, by Philadelphia Electric Company and 52 other utility companies comprising High Temperature Reactor Development Associates, Inc. This prototype HTGR will be the first power reactor in the nation to produce a reactor coolant outlet temperature of 1380 F., thus making possible modern steam conditions and high over-all system efficiency. In addition, the HTGR's design leads to important savings in fuel costs.

Sixty-four of the nation's investor-owned utilities are now participating in General Dynamics' programs in advanced nuclear power systems, controlled thermonuclear reactions and direct conversion of heat to electricity.

GENERAL DYNAMICS
GENERAL ATOMIC DIVISION

Illustration: two sections of nuclear assembly when brought together form critical experiment to study nuclear core characteristics of prototype HTGR.

WHAT HAPPENS WHEN A NATION SPENDS MORE ON GAMBLING THAN IT SPENDS FOR HIGHER EDUCATION?

If you can find any Romans around, ask them. They lived pretty high on the hog in their day. That is, until some serious-minded neighbors from up North moved in. The rest is ancient history.

You'd think their fate would have taught us a lesson.

Yet today we Americans spend twenty billion dollars a year for legalized gambling, while we spend a niggardly four-and-a-half billion for higher education. Think of it! Over four times as much! We also spend six-and-a-half billion dollars a year for tobacco, nine billion dollars for alcoholic beverages, and billions more on other non-essentials.

Can't we read the handwriting on the wall?

Our very survival depends on the ability of our colleges and universities to continue to turn out thinking men and women. Yet today many of these fine institutions are hard put to make ends meet. Faculty salaries, generally, are so low that qualified teachers are leaving the campus in alarming numbers for better-paying jobs elsewhere.

In the face of this frightening trend, experts estimate that by 1970 college applications will have doubled.

If we are to keep our place among the leading nations of the world, we must do something about this grim situation before it is too late. The tuition usually paid by a college student covers less than half the actual cost of his education. The balance must somehow be made up by the institution. To meet this deficit even the most heavily endowed colleges and universities have to depend upon the generosity of alumni and public spirited citizens. In other words, they depend upon *you*.

For the sake of our country and our children, won't you do your part? Support the college of your choice *today*. Help it to prepare to meet the challenge of tomorrow. The rewards will be greater than you think.

It's important for you to know what the impending college crisis means to you. Write for a free booklet to HIGHER EDUCATION, Box 36, Times Square Station, New York 36, New York.

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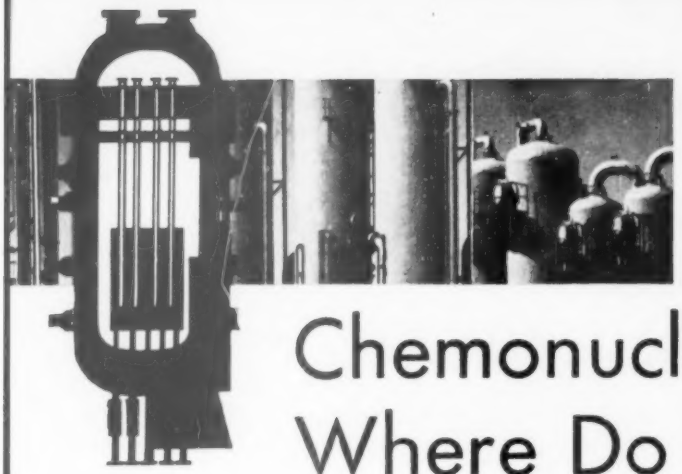


Chemonuclear Reactors—Where Do They Stand?

Fission-fragment recoil ionization energy can produce chemicals, but economic use in chemonuclear reactors is fraught with problems—fuel selection, reactor control, product decontamination and costs

NUCLEAR RADIATION is finding broad application in "chemical" processes—improving plastics, sterilizing pharmaceuticals and pasteurizing foods—with varying degrees of economic success. Accelerators and radioisotopes are the usual source of such radiation, but there's a vast untapped reservoir in the energy of the fragments recoiling from fission. But processes that involve radiations from radioisotopes only make use of the beta and gamma radiation given off by decaying products of fission—and their energy is never more than 6% of the total energy given off in fission.

To tap the energy of recoiling fission fragments, we must pass a process stream through a nuclear reactor whose core contains unclad fissioning uranium. But such chemonuclear reactors (as they have come to be called) ensnare us in problems—problems that encompass radiation chemistry, effective fuel form, safe reactor design, and decontamination of the processed fluid. These four hurdles are under attack by Rensselaer Polytechnic Institute, Brookhaven National Laboratory, Aerojet-General Nucleonics, Hercules Powder Co. and other groups.

What Is Being Done

Rensselaer's Harteck and Dondes in 1956 suggested the use of reactor radiation to extract nitrogen from air (*1*). The "fixed" nitrogen then could go into making chemical fertilizer (for which there is a 3-million-ton/yr U. S. market and a 12-million-ton/yr world market), nitric acid and similar nitrogenous compounds. Harteck and Dondes have extended their studies of fission-fragment chemistry to many processes and now have a test loop in the Brookhaven reactor.

In 1957 Aerojet started to study nuclear nitrogen-fixation under contract to Chicago's Union Stockyards and Transit Co., a large supplier of fertilizers (*2*). Aerojet followed this initial study with two irradiation tests for the USAEC in the LPTR at Lawrence Radiation Laboratory. Aerojet now is working to show the practicality of producing hydrazine in a reactor. Initial capsule tests in an AGN-201 reactor appear promising and LPTR capsule tests are underway (*3*). But some other investigators, such as Brookhaven, believe that the data so far do not justify a major development push yet (*4, 5*). They favor further basic study of the radiation chemistry of potential processes, fuel development and decontamination in a search for a solidly promising approach.

Hercules Powder Co. favors developing a chemonuclear reactor to make ethylene glycol (antifreeze) from methanol (*6*). The firm's optimism is rooted in reactor-irradiation experiments it sponsored at Argonne and Battelle Memorial Institute.

British and Belgian researchers at Harwell and the University of Liege (*7*), respectively, are studying potential yields and problems of various chemonuclear processes. Brookhaven, which has been using alpha and gamma radiation sources for its basic studies, recommends the construction of a versatile test loop so as to add fission fragments to the "tool supply" for investigating process kinetics.

The ability to produce nitric acid and hydrazine, which are rocket propellants, calls to mind the fact that chemonuclear reactors might find unique duties in space travel.

Reactor Design Considerations

The designer of a chemonuclear reactor is faced with a host of new problems—not only must he ensure criticality, structural integrity and shielding as in a power reactor, but he must make his fuel fine enough for fission fragments to escape and must deal with the resultant high radioactivity in the process loop.

Fuel type. Chemonuclear-fuel configurations that have been advanced include: very thin ribbons of metallic uranium, U_3O_8 particles coated onto plates, glass-fiber elements containing U_3O_8 (as studied by Rensselaer, Owens Corning, and Brookhaven), a "microporous" fuel (such as R. Cockelbergs is studying in Belgium), or U_3O_8 "dust" particles that circulate through the system (favored by Aerojet and Hercules).

Reactor stability. Because the process stream passes through the reactor core and the fuel might move within (or even through) the core, there is concern about the reactor's power stability. Aerojet and Hercules analyses have touched on this problem briefly, but Brookhaven calculations indicate the need for further study and experiments as process and reactor design trends crystallize (*5*). (*Continued*)

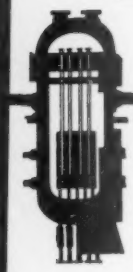
Product decontamination. Since the process fluid is irradiated by neutrons and loaded with fission products, it will be radioactive when it emerges from the reactor. These radioactive impurities must be removed. Aerojet says a decontamination factor of 10^3 is needed for nitrogen fixation—and that factors as high as 10^{16} can be achieved.

Economics—the key point. Opinion is mixed on the likelihood that chemical production using reactors will prove economical. It's a function of the product produced as well as the still-unknown reactor design. While Aerojet agrees with Brookhaven that nitrogen fixation might be marginal, Aerojet believes its hydrazine studies put chemonuclear reactors well within the economical range.

Brookhaven studies indicate that chemonuclear reactors whose sole function is to produce chemicals stand little chance of being victors in any price competition with conventional processes in the U. S., although the picture brightens somewhat if the reactor heat generates steam or electricity too. On the other hand, Aerojet believes a cooler single-purpose reactor is better.

Over-all, the future of chemonuclear reactors in the U. S. depends first on finding uniquely valuable processes that can compete with conventional alternatives—a competition made more difficult for chemonuclear reactors than for accelerators because they can't compete for low-volume-of-use products. But even with a favorable product technical problems, especially product decontamination, might prove inseparable. Still the opportunity to use the energy of fission-recoil is too significant to ignore. Experiments underway now will at least help refine our picture of the problems and potential.

—Bibliography is on page 50.



Chemonuclear Reactors

Thin Unclad Fuel Needed for Chemonuclear Reactors

To get the recoil energy of fission fragments into a process fluid the fissionable material must be in 1–10-micron particles or thin layers. Suitable fuel configuration remains a vital and unresolved question

To BRING THE fissionable fuel in a chemonuclear reactor close enough to the target material that the fission-fragment recoil energy can ionize the chemical fluid efficiently, the fuel must be finely divided. Two basic fuel concepts have been considered. In one, the uranium (in the form of a dust, liquid or gas) is mixed with the "coolant," which is the chemical feed gas or liquid. In the other concept solid particles of uranium are imbedded in glass filaments or made into ribbons or plates that are held stationary in the flowing feed fluid. Calculations indicate that several fuel shapes might be effective in getting at least 50% of the fission-fragment recoil energy into the process fluid.

Choice of the best fuel depends on fuel fabrication and reprocessing costs, safety and reactor design. At this point it is difficult to tie these down, but as we learn more about the physical, chemical and engineering characteristics of specific fuels comparisons will crystallize more quantitatively. These, together with realistic yield and efficiency data for various reactions and fuel configurations will point the way towards productive chemonuclear reactors.

Based on reactor design, flow dynamics and efficient use of the fission fragments, the optimum fuel-particle diameter or plate thickness is 1–10 microns and the most interesting reactor fuel loadings are 0.1–2 pounds of fuel per pound of process fluid.

Circulating Fuels

Since the fuel would circulate with the reactant fluid within the reactor core, there would be little structural material to absorb neutrons or fission fragments wastefully. Such a reactor could operate continuously, with a portion of the fuel being bled off for inexpensive reprocessing and recycling. Reactors with circulating fuel have a negative temperature coefficient of reactivity, which makes for inherent safety, but if the system ruptures fission products leak out easily and contaminate the area.

A critical problem would be the need for removing fission products from the product materials. Aerojet experiments indicate a decontamination factor of 10^3–10^{16} can be achieved for a nitrogen-fixation process (*8*). Although the reactor vessel could be of reasonable size and system components fairly conventional, there would be problems of erosion, corrosion, fluid dynamics, caking and separation.

Dust fuel in process gas. With 0.3–5-micron spherical particles of uranium oxide suspended in the flowing reactant gas, 50–95% (depending on particle size and spacing) of the fission-fragment recoil energy might produce useful reactions. Radiation damage to the fuel dust particles would be unimportant. But to minimize fuel inventory and erosion and settling problems in the piping system, nearly all the dust particles might be separated from the hot process gas before it goes to the external heat exchanger (cyclone separators in the reflector region might re-

move 95% of the fuel dust, then filters might remove 99.9% of the remaining dust). In a typical reactor for nitrogen fixation, the fuel dust and 1.6×10^6 lb/hr of gas would pass through the core in 16 passes via 200 tubes (each 187 ft long); there would be 0.11 gm U^{235} per gm N_2. With the gas at 1,000 psi, the reactor vessel would be only 9 ft in diameter, but large D_2O-moderator inventory might add to capital cost of some designs.

The figure shows the important relationship between the fuel particle size and energy deposition in the process gas. If pressure or temperature changes increase the gas density, the optimum shifts toward slightly smaller particles ($\geq$0.5 microns)—an increase in gas density raises the energy dissipation in the gas but does not appreciably change the optimum fuel loading (*9*).

Fortunately, there seems to be no great problem in keeping the dust-fuel particle size within the 1–10 micron range. Although settling time would be longer with smaller particles, in a "smoke-fueled" reactor with colliding 0.3–1-micron particles Van der Waal forces tend to make the particles adhere after collision. Particles of 10–100 microns break into smaller pieces when circulated continuously. But breakup of 1–10-micron particles is negligible because they don't have enough mass to cause fracture when they collide. Still, further agglomeration and attrition experiments are needed.

Liquid fuel solution or slurry. If the process fluid is a liquid, as in Aerojet's hydrozine design (*3*) the system could be quite efficient in its use of fission-fragment energy, but would have the erosion and corrosion problems of homogeneous reactors; as liquid-fuel reactors are developed, this concept could become more attractive. If the reactant fluid is a gas, it could be bubbled through the liquid fuel (as in a counter-current absorption column), but it would be very hard to get uniform gas dispersion in the liquid without extensive dispersion equipment.

Gaseous fuel in process gas. Uranium gas compounds that have sufficient vapor pressure under reactor conditions are halides, such as UF_6. But the chemical reactivity of UF_6 discourages its use as a reactor fuel.

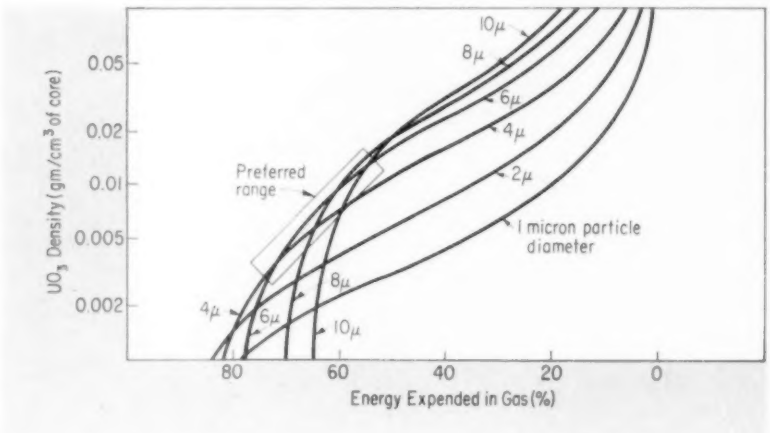
Fixed Fuels

As in most reactors built today, the fuel in a fixed-fuel chemonuclear reactor would be in a fixed array that is stationary in the coolant stream passing through the core. Because of this, the product would be less contaminated with uranium, but the necessarily small fuel dimensions and lack of clad make strength difficult to achieve. With fragile fixed-fuel arrays in the core, pressure drop and pumping power would tend to be high and coolant velocity would be limited, which might make it necessary to have heat exchangers within the core vessel. Structural materials in the fuel would depress neutron economy and release of fission-fragment recoil energy. Further, the reactor would have to be shut down periodically to change fuel, and intricate shapes and frequent reprocessing and refabrication might make fuel costs high. With a multitude of small fuel elements in the core, the core would be quite large and its pressure vessel difficult to fabricate. Worst of all, a gas-reactant-cooled fixed-fuel reactor would have a large positive temperature coefficient of reactivity, making reactor control difficult—and a leak in the system would result in loss of neutron-absorbing-gas and an increase in reactivity (*2*).

Glass fibers impregnated with U_3O_8. SiO_2 fibers impregnated with up to 50 wt % U_3O_8 have been made in diameters of 1–25 microns. For a chemonuclear reactor, 3–6 lb/ft³ reactant gas (having ~0.36 lb U^{235}/lb of gas) would pass through a porous mat of such 1–2-micron-diameter glass U_3O_8 fibers; in an Aerojet design (*2*) the mat could constitute the 1-in. cylindrical walls of a number of special structural fuel elements; about 46–80% of the fission-fragment recoil energy would be used effectively in the process gas. From the reactor, the product-rich gas would pass through a filter (which would remove entrained glass-U_3O_8 fragments) before going to the heat exchanger.

Glass fiber is chemically and thermally stable and has good tensile strength at elevated temperatures (glasses can be made with softening points above 1,000° C); such fuel elements would resist corrosion by highly oxidizing gas and could be manufactured rather easily by a conventional process. However, with the fibers packed loosely enough to minimize loss of fission-fragment recoil energy to adjacent fibers, the poor compressive strength of the mat would lead to its compaction as the coolant flows through it. Further, radiation damage to thin fibers could be a problem: when fission fragments recoil through the surface of a fiber they energize some surface atoms enough to disengage them—deteriorating the fiber. This would keep burnup below 12–18%.

Plate fuel. Plates, ribbons, or foils of U $\leq$5–10 micron thick could be sandwiched between a rigid open-mesh screen that supports them in an ordered array. The plates would be 1 mm apart (with 1,000-psi 800° F air as process fluid) so the fission fragments from one plate would not recoil into a neighboring one. For added strength and integrity, the U could be



OPTIMUM FUEL-PARTICLE size for reactor that uses fission-fragment recoil energy to chemically synthesize reactant gas at 20 atm and 600° C. As shown, optimum size is 4–10 microns, which for a UO_3 loading of 0.003–0.020 gm/cm³ results in depositing 50–70% of the fission-fragment recoil energy in the reactant-coolant gas

bonded to the screen by fusion or metal plating so that a break would not spread. About 45–75% of the recoil energy from such plates would be deposited in the process fluid. On the other hand, if stronger fuel elements are made by plating 1-micron thick U oxide on metal structure plates, half the fission fragments are absorbed in the substrate, so the efficiency of recoil energy deposition in the process fluid would be only 20–40%. Bonding the U to the plates in a corrosion-resistant layer would be a problem.

Porous bed. The U oxide deposit could be supported within a porous bed of silica or alumina, but because many fission fragments would recoil into adjacent atoms, less than 25% of the fission-fragment-recoil energy would be deposited in the process fluid.

* * *

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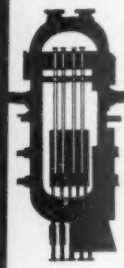

Chemonuclear Reactors

Fission Fragments Initiate Ethylene Glycol Synthesis

By ALLAN K. WIEBE, WILLARD P. CONNER, *Hercules Research Center, Hercules Powder Co., Wilmington, Del.* and GLENN W. KINZER, *Battelle Memorial Institute, Columbus, Ohio*

IRRADIATION OF METHANOL by fission fragments gives 0.1 lb of ethylene glycol per kwh with 65% chemical conversion (plus an additional 10% conversion to formaldehyde). These are the results of irradiations in two different types of reaction vessels in two nuclear reactors. While these yields are high, they probably can be increased by further research on the use of diluents (such as water or H_2) and chain transfer agents in irradiations above 150° C (*1*).

Fission fragments, each having about 20–22 unit charges at the instant of fission, produce short but dense ionization tracks. Molecules within this track are ionized or broken into ionized fragments, which react directly or combine with electrons to form neutral but extremely reactive fragments that then react by typical free-radical mechanisms.

Reactions

The reaction of methanol to produce ethylene glycol apparently involves primarily the combining of $\cdot CH_2OH$ radicals that arise either when H· is ejected from a neutralized parent ion CH_3OH^+ or when a free radical (H·, $CH_3\cdot$, CH_2:, etc.) extracts hydrogen from methanol:

$$CH_3OH + \begin{cases} H\cdot \\ CH_3\cdot \end{cases} \rightarrow \cdot CH_2OH + \begin{cases} H_2 \\ CH_4 \end{cases}$$

$$2\cdot CH_2OH \rightarrow (CH_2OH)_2$$

In the irradiated material, hydrogen extraction must compete with recombination of radicals such as H·, $CH_3\cdot$, and CH_2:. This recombination reduces the ethylene glycol yield. Unfortunately, hydrogen-extraction reactions require activation energies of about 7–10 kcal/mole, while free-radical recombination reactions require essentially zero activation energy (*2*). At room temperature radical recombination is much more likely to occur.

Three approaches have been used to increase the probability of hydrogen-extraction reaction: (a) use a diluent such as water to reduce the concentration of methanol fragments in the ionization tracks, (b) provide a lower-

TABLE 1—Irradiation of Methanol Vapor by Fission Fragments in CP-5

Reactants	*Temp* (°C)	*Conversion* (*mole %*)	$(CH_2OH)_2$ *yield* (%)	*Energy consumed** [*kwh/lb* $(CH_2OH)_2$]	*Energy consumed** [*ev/molecule* $(CH_2OH)_2$]
CH_3OH	150	6.1	50	7.4	37
CH_3OH	250	7.3	51	7.6	39
CH_3OH	150	15	31	9.8	50
$CH_3OH + H_2O$†	150	6.2	67	7.2	36
CH_3OH + 1% CCl_4	150	8.3	66‡	4.2	22

* Fission-fragment energy only; we measured the very small contribution from gammas and neutrons in a blank experiment and subtracted it from the gross energy. † In equimolar quantities, conversion is based on total reactants. ‡ We estimated ethylene glycol yield from material balance and C:H:O ratios because we lost much of the bomb washings (see Table 4).

energy path for hydrogen extraction, (c) take advantage of a reaction temperature that would favor hydrogen extraction.

Photochemical studies (*3*) indicate that hydrogen chloride and the chloromethanes provide low-energy paths by which a hydrogen atom might be extracted from a methanol molecule. Theoretically, the activation energy can be reduced from 7–10 kcal/mole to about 4 kcal/mole. The concentration of chlorine atoms must be carefully controlled at a low value.

Since the reaction rates of high-activation-energy processes have much larger temperature coefficients than do the rates of low-activation-energy processes, higher temperatures should increase the probability of hydrogen extraction per collision while having very little effect on radical combination. The photolysis of acetone at 100-mm pressure with 2,537-A radiation (*4*) follows this simple kinetic picture. The ratio of hydrogen-extraction reactions ($CH_3\cdot + CH_3COCH_3 \rightarrow CH_4 + \cdot CH_2COCH_3$) to free-radical recombination reactions ($2CH_3\cdot \rightarrow C_2H_6$) is 1:9 at 120° C, but 12:1 at 300° C. High temperatures should similarly favor glycol production.

Argonne Irradiations

Methanol irradiation experiments were designed to show the effects of temperature, dilution with water, and addition of carbon tetrachloride. Six methanol-vapor samples were irradiated in Argonne's CP-5 reactor and 12 samples in the reactor at Battelle Memorial Institute.

Table 1 shows that in the irradiation of a 0.31-mole sample of ~0.1-mole/liter methanol vapor at 150° C to 6.1 mole % conversion, a yield of 50% was obtained with an energy input of 7.4 kwh/lb of ethylene glycol. In comparison with this result, it was found that: (a) for irradiations of undiluted methanol, raising the temperature to 250° C had little effect on glycol yield and energy requirements; (b) raising conversion to 15% adversely affected chemical yield and energy input; (c) diluting the methanol with 50 mole % water raised the glycol yield to 67% but did not affect the energy required per pound; and (d) adding 1% CCl_4 to undiluted methanol increased the yield to 66% while reducing energy needed to 4.2 kwh/lb of glycol. Only trace amounts of formaldehyde were found, probably as a result of slow chemical reaction of this product with other constituents during the several months the products were in the reaction vessels to allow the induced radioactivity to decay enough to permit handling.

TABLE 2—Battelle Irradiation of Methanol Vapor

		Reactants			*Product yield*	
Experiment	*Temperature (°C)*	*$CH_3OH + H_2O$ (mole)*	*H_2O (mole fraction)*	*CCl_4 (10^{-5} mole)*	*Ethylene glycol (%)*	*Formaldehyde (%)*
1	*150*	*0.123*	*0.5*	*0*	*42*	*3.8*
2	*150*	*0.123*	*0.5*	*0*	*46*	*4.5*
3	250	0.30	0.6	50	13	5.2
4	250	0.10	0.4	50	29	9.2
5	250	0.10	0.6	10	31	8.6
6	250	0.30	0.4	10	31	3.5
7	*150*	*0.123*	*0.5*	*<1?*	*61*	*6.9*
8	150	0.30	0.6	50	47	10.1
9	150	0.10	0.4	50	47	22
10	150	0.10	0.6	10	66	12.3
11	150	0.30	0.4	10	65	9.2
12	*150*	*0.123*	*0.5*	*<1?*	*65*	*7.1*

Conversion was 3–6%. Experiments 1, 2, 7 and 12 were control experiments to monitor the condition of the reaction vessel; 1 and 2 were run in the new reaction vessel, but since 7 and 12 were run after a series of experiments using CCl_4 as a reactant we attribute their higher yields to traces of chlorides remaining in the vessel (although it is possible that traces of some organic product or fission product might have been the cause).

Battelle Irradiations

The irradiations at Battelle (Table 2) showed again that low concentrations of carbon tetrachloride markedly raised yields. Possibly at variance with the Argonne results are the Battelle runs with the $CH_3OH—H_2O—CCl_4$ system at 250° C and 150° C, where the higher temperature gave lower chemical yields. Dilution with water showed the expected improvement, but variations in water content within the range 40—60 mole % did not seem to affect glycol yields, except for the higher-CCl_4 samples at 250° C. Table 3 shows the generally excellent agreement between the experiments at Argonne and those at Battelle.

Experimental Methods

To coat the U_3O_8 uniformly on the inside surfaces of each reaction vessel (Fig. 1) we introduced 25 ml of an ethanol solution of uranyl nitrate and evaporated the ethanol solvent with an air stream while the vessel was rotated in a horizontal position. We then heated the vessel to 350° C for several hours to make the U_3O_8 film insoluble and tightly adherent. For the Battelle vessel (Fig. 2), thicker films were made up of several layers laid down from similar alcoholic uranyl nitrate solutions.

After each reaction vessel had been irradiated and removed from the Argonne reactor, we removed the outer container and electrical equipment and then we stored the vessel until the induced radioactivity decayed to a safe level (100 mr/hr at the

TABLE 3—Requirements for Producing Ethylene Glycol*

	Battelle	*Argonne*
Ethylene glycol yield, %	65	67
Formaldehyde yield, %	11	?†
lb CH_3OH/lb $(CH_2OH)_2$	1.5	1.5
kwh/lb $(CH_2OH)_2$	10.2‡	5.7‡

* Each set of data is the mean of the two best experiments at each reactor. † We found no HCHO; however, products had remained in reaction vessel for several months while it cooled enough to handle. ‡Discrepancy might be caused by our estimates of depressed neutron flux at UO_2 film and of how much fission-fragment energy escapes from film.

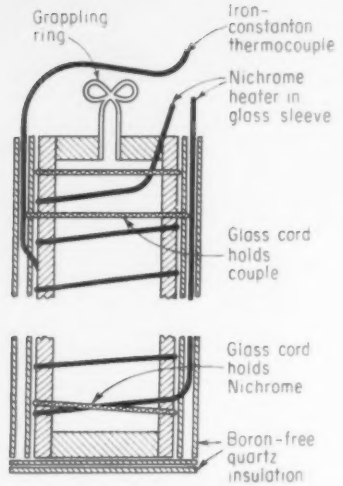

FIG. 1. ARGONNE IRRADIATIONS USED 2.9-liter Al cylinder of 1,500-cm² inside surface coated with 20%-enriched U_3O_8 0.1–0.2 micron thick. To minimize evaporation losses, samples were inserted via 12-in. hypodermic into vessel. Then vessel was evacuated, welded shut and irradiated in CP-5 17–34 hr in 1.2×10^{12} n/cm²/sec

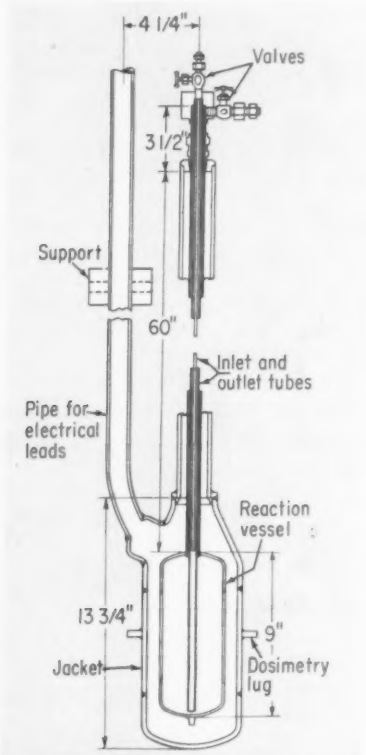

FIG. 2. BATTELLE IRRADIATIONS USED 1.14-liter 3-in.-dia ss vessel with ss concentric inlet and outlet tubes. Wires to heaters and 16 thermocouples (not shown) within He-filled Al jacket, passed through Al pipe at left. Film on inner surfaces was 88%-enriched U_3O_8 1 micron thick. Flux was ~10^{12} n/cm²/sec for 5–10 min

surface). Then the vessel was put in a vacuum-tight container of known volume, the container was evacuated, and the reaction vessel was punctured so the gases escaped into the known volume. Pressure and temperature were measured to determine the moles of gas. Both liquid and gas samples were saved for analysis.

Gas samples were analyzed by mass spectroscopy, ethylene glycol determined by periodate oxidation (*5*), formaldehyde by the chromotropic acid (*6*) and polarographic (*7*) methods, and acetaldehyde measured polarographically (*7*). Table 4 shows the excellence of the material balances.

Since all the Battelle experiments used the same reaction vessel, we washed the vessel with two 1-liter aliquots of methanol before each irradiation so as to remove any residue from the previous reactants or products that might coat the uranium film or otherwise affect the next experiment.

After each irradiation at Battelle, we bled off the gaseous products and then rinsed the vessel. This made it impossible to establish material balances, but they did not seem important after the excellent Argonne balances.

Dosimetry. Since the values for the integrated thermal-neutron flux used to calculate fission-fragment energy input to the reactants was probably our greatest uncertainty in the Argonne experiments, we considerably refined the neutron dosimetry for the Battelle experiments. We determined the average neutron flux immediately surrounding the reaction system for each experiment by measuring the radioactivity induced in cobalt wires on the reaction vessel. An initial mockup experiment showed a factor of 1.14 between the thermal-neutron flux across the uranium-oxide film within the reaction vessel and the flux across the outer surfaces. Dose measurements based on the radioactivity induced in these cobalt wires agreed excellently with calculations based on xenon-135 activity in the off-gases. We estimate the contribution of incidental gamma-rays and neutrons to the total products at less than 5% of the total.

* * *

For the Argonne experiments, the containers were made, filled and sealed at the Hercules Research Center. Irradiation on a service basis was carried out in CP-5. Product recovery and decontamination were carried out by Nuclear-Chicago Corporation under contract to Hercules. All analyses were made at the Hercules Research Center.

All work on the Battelle experiments was carried out by Battelle Memorial Institute under Hercules sponsorship.

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TABLE 4—Material Balance of the Recovered Products after CP-5 Irradiation

		*Methanol equivalent of irradiated reaction mixture**							*Discrepancy in balance*	*Reactants found*
Expt	*Reactants (gm)*	*Distillate (gm)*	*$(CH_2OH)_2$ (gm)*	*HCHO (gm)*	*CH_3CHO (gm)*	*CH_4 (gm)*	*CO (gm)*	*Total (gm)*	*(gm)*	*(%)*
1	Blank	Negligible products								
2	10.1	9.46	0.317	0.042	0.010	0.070	0.182	10.03	0.07	99
3	8.1	7.68	0.307	0.006	0.017	0.064	0.192	8.24	−0.14	102
4	10.1	8.48	0.478	0.009	0.015	0.118	0.326	9.40	0.70†	93
5	7.83	7.30	0.330	0.007	0.006	0.029	0.109	7.77	0.06	99
6	10.1	9.28	0.062	0.009	—	0.080	0.173	9.60	0.50‡	95

* Methanol equivalent of reaction products is based on carbon content (1 atom of C in the product = 1 molecule of CH_3OH in the starting material). † Expt 4 was subjected to double the power input; the high conversion probably resulted in secondary reactions leading to high molecular weight and, thus, unrecoverable product. ‡ We lost much of the reaction-vessel rinsings, so this discrepancy probably represents lost ethylene glycol.

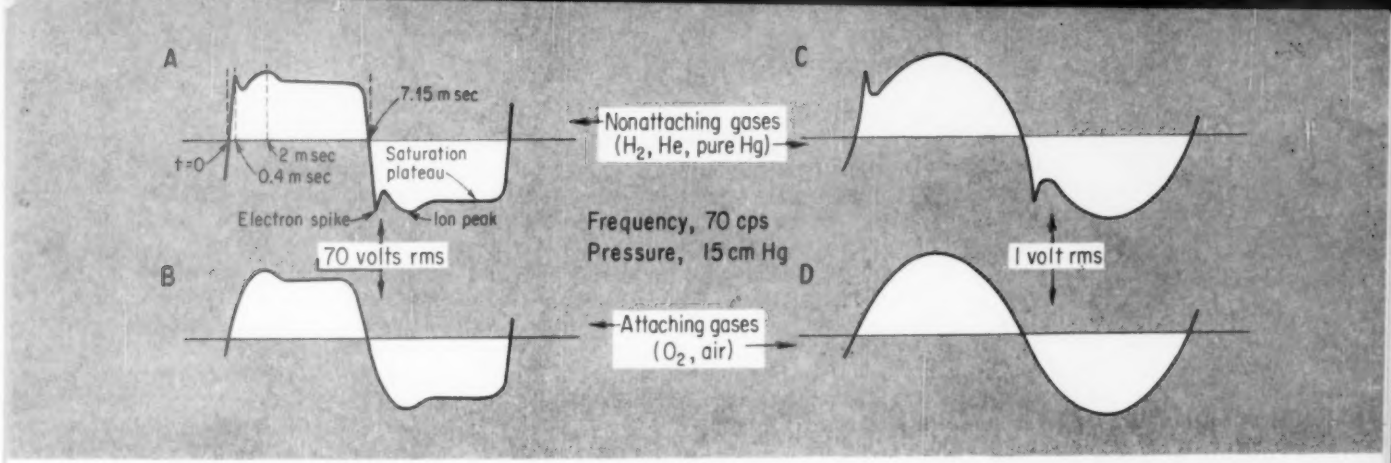


FIG. 1. CURRENT-OUTPUT WAVEFORMS FROM A-C OPERATION show effects of increasing polarizing potential and changing filling gases from those that readily attach electrons to form negative ions (electronegative gases) to those that do not

A-C Ionization Chambers Are Simple and Reliable

Problems of d-c-polarized chambers—large polarizing voltages, insulated leads, large signal impedances, voltage stabilization, d-c amplification—disappear with stable, sensitive a-c operation

By DAVID L. ROBERTS, *U. K. Atomic Energy Establishment, Winfrith Heath, England*

IONIZATION CHAMBERS polarized by d-c voltages have been used for radiation measurement almost from the discovery of X-rays. Operation of an ionization chamber with alternating voltages has been more recent (*1, 2*). An investigation into a-c operation undertaken at Harwell in 1958 has largely confirmed hopes that a-c technique will, for example, simplify the instrumentation of a reactor shutdown channel. A new fail-safe feature has been provided by using a continuous self-monitoring arrangement such that immediate indication is given of any break in the loop containing the a-c oscillator, detector and amplifier. These advantages have been gained without sacrifice of either sensitivity or stability.

Our experimental work on this subject has been with boron-lined neutron-measuring chambers. Two modes of operation are possible: a low-voltage mode, in which one takes advantage of the linear chamber response for small collecting potentials, and a high-voltage mode, in which one achieves saturated collection and increased ranges of operation. Current waveforms (Fig. 1) depend on the mode of operation, the frequency of the polarizing potential and the nature of the filling gas. Many applications are possible; ours so far have been to reactor control and shutdown circuits.

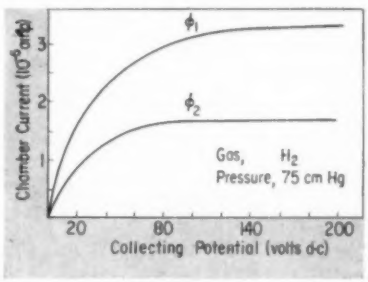


FIG. 2. D-C RESPONSES for chambers used in these experiments at two neutron fluxes have linear portions at low voltages, saturation at voltages > ~140 volts

Ionization Chamber

For convenience we have used the British standard type RC/1 ionization chambers in our experiments. These consist of two concentric aluminium electrodes with a radial spacing of 6 mm in a sealed aluminium case. Each electrode is coated on the side facing the 180-cm³ active volume with a boron deposit, which, under thermal-neutron bombardment releases alpha particles from B^{10} with total reaction energies of 2.8 and 2.3 Mev.

Electrons and positive ions produced by an ionizing particle have different mobilities in the applied field. This is unimportant in normal d-c operation since the field and ion densities redistribute themselves after a time slightly longer than the transit time of the slowest ions across the gap. Then both types of ions contribute equally to the ionization current. With an alternating polarizing voltage the field and ion densities can redistribute

themselves in each half cycle producing transients in the output waveform. Under some conditions, which I will discuss later, these transients do not exist.

Quiescent Operation

The response curves in Fig. 2 show currents collected from our ionization chambers as functions of d-c potentials applied to them and for two values of neutron flux. At large potentials the current is independent of applied potential since all ionization is collected. At smaller potentials some ions can recombine before they are collected; hence the current is smaller. If we consider ion collection only at very small potentials we can make two assumptions: (a) the applied field is too weak to affect recombination rate; loss of ions is almost entirely by recombination; (b) any distortion of the uniform applied field between electrodes can be ignored. The current density (amp/cm^2) extracted from the chamber is (*3*)

$$j = k^+ \frac{eX}{\rho^{1/2}} \left(\frac{dN}{dt}\right)^{1/2} + k^- \frac{eX}{\rho^{1/2}} \left(\frac{dN}{dt}\right)^{1/2} \quad (1)$$

[e = electron charge; k = ionic mobility; ρ = recombination coefficient; X = field strength (volts/cm); dN/dt = rate of ionization production (ion pairs/cm^3 of gas/sec), which is proportional to neutron flux].

Equation 1 shows that output current is directly proportional to field strength X, and therefore to applied voltage. We have verified this linearity at the low-voltage end of the response curve using both d-c and a-c voltages, and it holds for a-c voltages up to 1 volt rms. An obvious advantage of this linearity is that the chamber can form part of a linear bridge network and the bridge output can be made independent of small variations in supply voltage.

In testing the current-flux relation of Eq. 1, we found the current proportional to $(dN/dt)^{0.6}$. This value of the exponent is greater than we had expected, but it is reasonable to suppose that it would in practice be larger than the 0.5 of Eq. 1 because ion diffusion to the walls has been ignored and because of other limitations in our assumptions. We have found a rigorous theory with ion-diffusion effects and collection of current included is too difficult to pursue. But our measurements show that the exponent of dN/dt is constant over a range of flux from 10^8 to 10^{11} n/cm^2/sec and voltages up to 1 volt rms.

The other factors in Eq. 1 can be considered constants for static chamber conditions of pressure, temperature and filling gas.

If now we consider the saturated portion of Fig. 2 (applied voltage great enough to collect all ions) there is no recombination and the saturation current is given by

$$j_s = es\, dN/dt \quad (2)$$

(s is electrode spacing) (*3*).

In addition to a difference in output currents between strong- and weak-field states, there is a large difference between ion densities. In saturation the volume contains only those ions that are in transit to the electrodes and hence ion density is very small. In a weak-field condition ions are lost by recombination and a large ion density is given by an equation describing an equilibrium between ion densities and recombination

$$-\frac{dN}{dt} \approx \rho N^+ N^- = \rho N^2$$

$$N = N^+ = N^- = -\frac{1}{\rho}\frac{dN}{dt} \quad (3)$$

Sine-Wave Response

As one can anticipate from Eqs. 1 and 2, the current waveform from an a-c-operated chamber depends on frequency and amplitude of the applied potential. It depends also on the nature of the filling gas. Figure 1 shows representative waveforms that we get with a capacitance balance (Fig. 3), used to cancel the capacitance of the chamber (~50 $\mu\mu$f) and enable observation of the ionization alone.

Strong-field waveform. In saturated a-c collection (Figs. 1A and 1B) applied voltage is large enough to saturate the chamber. During the weak-field period at the beginning of each half cycle very little ion current is extracted from the ionized gas. Thus ion density builds up toward the equilibrium density given by Eq. 3. The extent to which this density is achieved is governed by the duration of the weak-field condition.

As the voltage rises the electrons are the first to be significantly influenced by the field and surge toward the positive electrode. This movement of negative charge causes the electron spike of Fig. 1A, which has a magnitude limited by either formation of negative ions or by collection of all available electrons from the volume. The absence of the electron spike in Fig. 1B is explained by the presence in the filling of gases that readily acquire electrons to form heavy negative ions. I will discuss this point in greater detail later.

As the voltage continues to increase after the formation of the electron spike, an accumulating number of positive ions move with increasing velocity to the negative electrode. This increasing movement of charge gives rise to the ion peak which reaches its limit when saturating voltage is reached and the volume has been stripped of all ions that have accumulated during the weak-field period. Finally, as long as the applied voltage is greater than the chamber saturation voltage, a constant current is extracted giving the saturation plateau.

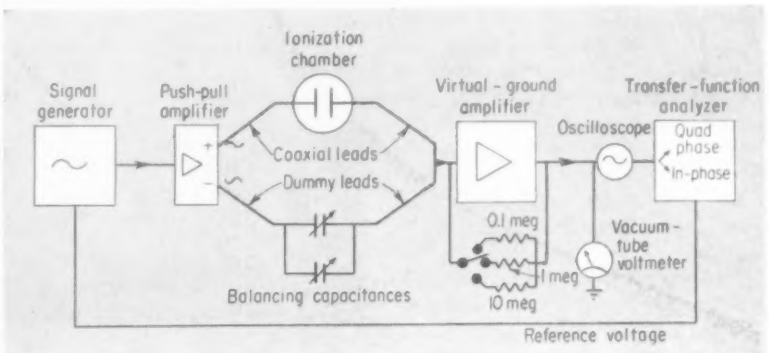


FIG. 3. CAPACITANCE BALANCE EVALUATES OUTPUT by comparing both in-phase and quadrature (90 deg out-of-phase) components with signal-generator reference

Weak-field waveform. When a small a-c potential is applied so that a weak-field condition is maintained over the whole cycle, Eq. 1 indicates a sinusoidal response with no changes in the amount of recombination.

Since the electrons are still much more influenced than the heavy ions, however, there must still be an electron surge at the beginning of each half cycle (Fig. 1c). Fig. 1D, like Fig. 1B shows elimination of the electron spike in electronegative gases.

Square-Wave Response

We noticed that the times at which the electron spike and the ion peak occur are determined more by the sinusoidal form of the polarizing voltage than by transit times of ions. To verify this suggestion we used a rectangular polarizing waveform in which pulse amplitude, pulse duration and time interval between pulses were all variable. For a time between pulses of the order of milliseconds, the gas attains fully its equilibrium ion density and upon application of the square pulse the waveform of Fig. 4 results. The electron spike is too fast to be detected (~ 1 μsec in duration) and the ion peak occurs in 15 μsec. With no time delay between positive and negative pulses, however, there is no evidence of an ion peak. This agrees with our theory since the polarizing voltage reverses too quickly to permit any change in ion concentration during the weak-field period; hence there is no accumulation of charge to be collected. The only distortion under this condition would be from the deceleration and acceleration of the ions as they reverse their velocities. Calculation shows that this occurs in millimicroseconds and thus would not be noticeable.

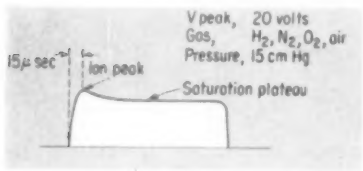


FIG. 4. SQUARE-WAVE RESPONSE shows ion peak (here) when pulse separation is great enough to permit ion accumulation. Peak disappears as separation is reduced

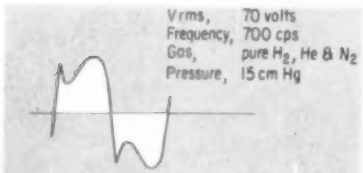


FIG. 5. HIGH-FREQUENCY OPERATION eliminates plateau since formation of ion peak takes most of available half-cycle

Frequency Dependence

If frequency of the sinusoid is increased from the 70 cps of Fig. 1, the field rises and falls more rapidly, but ion collection still takes a finite time and thus occupies a comparatively longer period in each half cycle. Eventually at 700 cps (Fig. 5) there is no saturation plateau since by the time the ion peak has been established the half cycle is nearly over.

This higher-frequency mode of operation has revealed another effect, however, which we call "resonance." Consider an applied chamber voltage large enough to collect all electrons as they are formed (and thus prevent their recombination) while the heavy positive ions still move relatively slowly towards the electrode. If this condition is coupled with an operating frequency of period less than the mean transit time of the heavy ions across the gap, very few positive ions will actually be collected. Instead, since ions are being produced at a constant rate and are not being collected at this rate, they oscillate in the gap and increase their concentration, until the ion density is limited by diffusion. This increase in total movement of charge results in a greater output current than is possible in the normal saturated mode.

For weak-field, uniform-collection conditions there is no ion peak or plateau, and changes in frequency simply alter the relative position of the electron spike, the distortion caused being less marked at low frequencies. Moreover lower frequencies produce a greater ratio of chamber ionization current to capacitance current. Since frequencies much less than 50 cps cause difficulties in measuring-system design and since it is necessary to avoid pickup from the 50–60-cps line frequency, we compromised on 70 cps as our operating frequency.

Filling Gases

The character of the electron spike depends on the filling gas. If an electronegative gas with a large attachment coefficient is used, free electrons readily attach themselves to form heavy negative ions, and the fast initial electron collection is eliminated. (Only a few gases are sufficiently attaching to show the effect—oxygen, air, chlorine, iodine and bromine.) An additional requirement for practical purposes is that the gas one uses be stable under prolonged irradiation. Both oxygen and air have been used successfully to eliminate an electron spike but neither is stable under irradiation. The deterioration of air was demonstrated when the gas in a chamber, filled to 15 cm Hg, degenerated from attaching to nonattaching after irradiation for 5 days at 10^{11} n/cm²/sec. Subsequent calculations and analysis of the gas verified that the oxygen content of the air had been reduced so much that heavy-negative-ion formation was not possible (4).

Many experiments were carried out with hydrogen, helium and nitrogen from commercial gas cylinders (99% pure). All attempts to display fast electron collection were fruitless. When each of these gases was spectroscopically pure, however, an electron spike was always obtained. Thus small traces of impurities in what should be clearly nonattaching gases can make the mixture behave as an attaching gas. The fact that certain inert gases can behave electronegatively when they contain traces of impurities may be very useful. When these impurities are finally identified they can be used to dope an inert filling gas to produce a chamber particularly suitable for a-c operation.

In our experiments to determine a suitable over-all system for a-c operation, whenever an attaching gas was required, we used air, but only for short irradiations.

Pressure, Temperature

A pressure increase above the 15 cm Hg of Fig. 1 increases the amount of

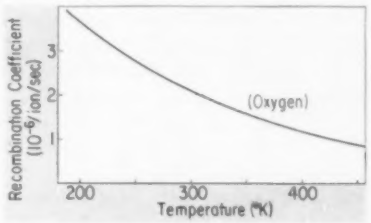


FIG. 6. TEMPERATURE EFFECT on recombination coefficient, shown here for oxygen causes some temperature effect on output

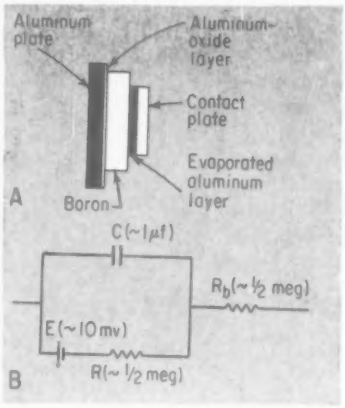
Electrical Properties of Boron Coatings Explain Anomalous Behavior

Question: With pure hydrogen, helium and nitrogen fillings, why do we find the expected electron spike with B^{10}-enriched coatings but not with natural boron? Answer: The anomaly comes from electrical characteristics of the coatings. Differences between the two types come from the ways in which they are applied.

Boron used on the electrodes was obtained as a colloidal suspension, enriched boron in a heavy mineral oil and natural boron in white spirit (a volatile petroleum product intermediate between gasoline and kerosene). The only difference in application was that the natural-boron coating contained twice as much of the suspension and hence had twice the thickness of the enriched coating. Since these facts do not explain the difference in performance, we began studying electrical characteristics with the samples of Fig. A, some with an aluminum coating to make contact with the boron, some with a stainless-steel base plate.

By measuring voltages as functions of currents (10^{-10} – 10^{-6} amp) in the feedback loop of a virtual-ground d-c amplifier we derived the equivalent circuit of Fig. B. Typical values for enriched coatings (measured at 10^{-6} amp and atmospheric humidity) are as follows: E = 0, R not detectable, R_b = 0.56 megohm, C = 20 μf. For natural coatings the corresponding values are, E = 40 mv, R = 0.3 megohm, R_b = 0.6 megohm, C = 9 μf.

Variation of E with humidity convinced us that its origin is electrolytic. R_b has been shown to be the resistance of the boron; R appears to arise in the aluminum oxide, and C to be an electrolytic capacitance.



BORON COATINGS (A) show electrical properties that depend on mode of application. Equivalent circuit (B) successfully explains anomalies of behavior in chambers coated in different ways

ionization within the active volume of the chamber. A smaller fraction of the ions produced is collected since the recombination is increased; in other words the chamber requires a greater voltage to saturate it. It is important for weak-field operation, therefore, to choose high enough pressure that the chamber is far from saturated by the required applied voltage.

Temperature-induced variations in output can be expected in weak-field operation for two reasons: the recombination coefficient changes as indicated, for example, in Fig. 6, for oxygen, and impedance of the semiconductor boron coatings changes with results that I will discuss presently; this latter effect can, however, be eliminated. Our experiments show that in weak-field operation output drops ~10% as the temperature is raised over a range of 75° C although the shape of the output waveform does not alter. In the saturated mode there is no change in output, however, since there is no recombination in this mode and the applied voltage is too great to be affected by any changes in the coatings.

As you will see from the box on this page, we found an unexplained variation of response between chambers that had enriched-boron coatings and those that had natural boron. The effect turned out to be an artifact associated with the mode of application of the coatings and their resulting electrical properties. Differences between the equivalent-circuit values of the two types of coating are more than large enough to account for the anomalous behavior we observe. For a flux of 10^5 m/cm²/sec, for example, the electron spike has an amplitude of 10^{-6} amp, causing a potential drop of 0.9 volts in the resistance of a natural coating, 0.9 megohms. This potential is to be compared with the applied voltage of 1.2 volts at the time of the electron spike, 0.4 msec after the start of the cycle.

Capacitance in the electrodes explains another effect. On application of a d-c potential to a chamber there is a transient of 30-sec time constant in which the current immediately rises to a peak and decays exponentially to a constant lower level. Also immediately after the transfer from d-c to a-c operation there is a d-c bias on the output that decays in a time comparable with the 30-sec transient. The explanation lies simply in the charging and discharging of the capacitance in the coatings.

As a final check to prove the existence of coating effects, an aluminum film was evaporated over a set of electrodes ensuring a good short circuit to the respective electrode. This arrangement removed all the anomalies.

Applications

We see that two distinct modes of a-c operation are possible: the weak-field mode and the saturated mode; in either, the electron spike can be eliminated by using a suitable filling gas as indicated in Fig. 1.

The output from the weak-field linear mode is a sine wave in phase with the polarizing voltage and of magnitude proportional to $\phi^{0.6}$. In addition there is a quadrature current, 90 deg out of phase with the polarizing voltage, derived from the capacitance of the chamber. This linear mode provides a useful output signal that is easily handled by reliable and standard a-c electronics and further permits one to use a linear bridge network. Such use implies that the ionization current can be balanced at the input to the amplifier—a fail-safe aspect—and an additional safety feature can be provided by the capacitance current, which can be continually monitored by using a phase-sensitive network. The principle application of this is in a reactor shutdown channel, which I shall presently describe.

Alternatively, the saturated mode of operation develops an essentially square-wave output in phase with the sinusoidal polarizing voltage, and directly proportional to ϕ in magnitude. This mode retains the fail-safe aspects of the weak-field mode and in addition it offers a measurement of a wider flux range since no upper limit is imposed on the operating voltage required to cover many decades of flux. The principle applications of this method of operation are, once again,

in shutdown-channel use and also in a fail-safe, self-monitoring, automatic control system. Its application for automatic reactor control comes from the a-c signal; one can easily detect the in-phase sinusoidal component and use it directly as a control signal.

Reactor Shutdown Channel

Figure 7 shows the essential features of a weak-field-operated shutdown channel. The in-phase ionization current I_c is backed off by the current I_r produced from the push-pull supply and a variable resistance. The two currents I_c and I_r will be out of phase and the net current is a measure of the difference between I_c and the preset I_r, which will, in fact, represent a reactor shutdown power. In addition, there will be a quadrature current I_q of a magnitude determined by the polarizing voltage ($\sim$1 volt) and the chamber capacitance, and this current can be adjusted by introducing some capacitance into the balancing arm of the bridge circuit. The net complex current is connected to the low-impedance input of a virtual-ground amplifier, this arrangement helping to reduce any noise in the long chamber leads. The amplified signal can now be used to operate phase-sensitive relays and a power-deviation meter.

The in-phase sensitive relay is set to remain energized as long as $I_r > I_c$. If, however, the reactor power increases so as to make $I_c > I_r$ then the resultant phase will change and de-energize the relay to cause a reactor shutdown. Similarly if I_r itself fails for any reason the relay will de-energize. In addition the quadrature-phase relay is energized by the quadrature current and any failure of this current due to an oscillator, amplifier or chamber failure, will de-energize the relay and initiate a warning.

When the ionization chamber is operating in the linear mode the current is proportional to $\phi^{0.6}$. To simplify the reactor control one must either wind the resistance R to a 0.6-power law or, more conveniently, calibrate its scale to this law. To enable the meter to display accurate readings for all preset power levels one must change its sensitivity in correspondence with the preset resistance. This can easily be arranged by, say, coupling a variable resistance of the meter circuit to the preset resistance control.

Value of A-C Operation

An ionization chamber operated from an a-c source has the advantages of low drift and relative simplicity. The signal from such operation can be analyzed for three properties: amplitude, phase and frequency. For the shutdown use described, the phase-sensitive relays rely on all three parameters and failure of any one, compared with the reference voltage, would cause the relays to trip. This constitutes a large measure of fail-safe response. An additional safety feature is provided by the quadrature monitoring current, which is sensitive to any break in the loop. The deviation meter is also sensitive to phase and frequency and is thus not liable to false readings from spurious signals unless these happen to be of the right frequency and phase. In gaining these properties the system does not lose the advantage of the d-c system of being independent of small variations in the polarizing voltage. Clearly such variations will affect each arm of the bridge in the same manner.

The reactor shutdown system described uses small polarizing voltages and derives small signal currents. These lend themselves readily to generation, amplification and display by transistor circuits. Thus it is possible to manufacture a small, compact set of equipment requiring only a small battery capability, the use of batteries giving what is virtually a guaranteed supply. This compares favorably with the bulky mains- and battery-operated d-c system both in elegance and in the amount of control-room space required to house it.

The sensitivity of the ionization chamber when used in the low-voltage mode is less than $\frac{1}{20}$ of that of saturated operation, although this is somewhat compensated for by using a-c techniques with their resultant reliability and stability. It is worth pointing out that the low-voltage mode is not the only method of putting a-c operation to work. It is possible to use saturated a-c operation and, say, sample the plateau height on each half cycle, or even to use squarewave polarization and either measure the rms value or again sample the plateau height. Both these methods increase detection sensitivity and yet retain some advantages of a-c operation. Our experiments in this investigation have been carried out in fluxes between 10^7 and 10^{11} n/cm²/sec, however, and in all cases a useful output has been obtained with polarizing voltages between 0.1 and 1 volt.

Finally there is no reason to suppose that an a-c system would be any more expensive than a d-c one. They both use the same types of component and, in fact, a transistor a-c system has the advantage of consuming very little power in operation.

* * *

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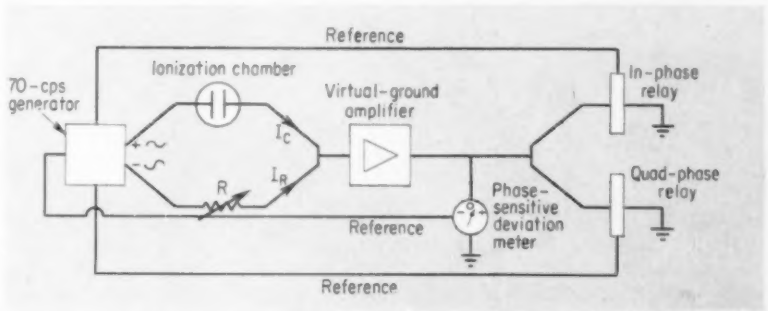
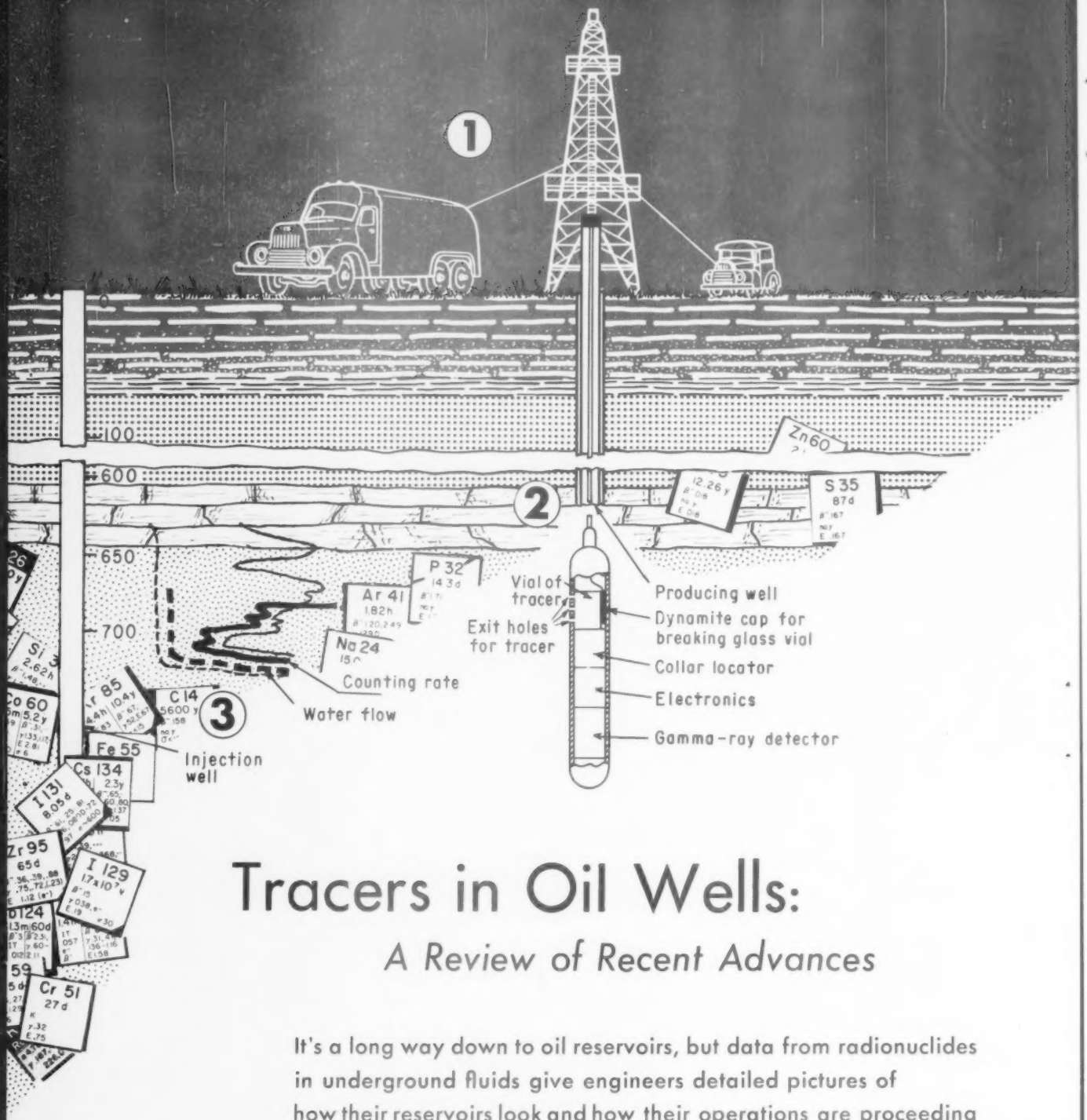


FIG. 7. REACTOR-SHUTDOWN CHANNEL separates in-phase and quadrature-phase components of chamber current, displays phase deviation and operates both in-phase and quadrature-phase relays. Any break in loop causes fail-safe performance



Tracers in Oil Wells:

A Review of Recent Advances

It's a long way down to oil reservoirs, but data from radionuclides in underground fluids give engineers detailed pictures of how their reservoirs look and how their operations are proceeding

By RICHARD L. CALDWELL, *Socony Mobil Oil Co., Dallas, Texas*

1 OIL-WELL OPERATIONS use instrument truck near well and derrick truck farther away. Most logging operations are performed by service companies and are available on short notice wherever oil is produced.

2 TRACERS ARE ADDED either at surface, at bottom of well through drill hole or at some other chosen level from especially designed container in logging tool. Dynamite cap releases tracer on signal from operator.

3 INJECTION WELL stimulates oil production when water moves from it to producing well, pushing oil before it. Tracers in injection well show rate and direction of water flow, nature of beds and rock fractures.

IN OIL FIELDS throughout the world radionuclides are helping engineers increase oil production (*1*, *2*). Engineers use tracers mainly to follow underground fluids, both liquid and gaseous. Sometimes the purpose is just to find out where certain fluids are, for example, in well logging, waterflooding, determinations of oil-water contacts and gas–liquid-propane injections. Sometimes one is concerned rather with the nature of underground formations, as in following the progress of fluids used for fracturing and acidizing and in determining causes of circulation loss. Another use of tracers is to mark an underground position: the location of cement in a well or a gas-water interface in an underground salt dome.

Logging Operations

When radionuclides are used in logging operations (Fig. 1), the procedure starts with a background measurement of natural gamma activity before the engineer puts any radioactive material into the well (*3*). After application of the tracer, either directly into the well or indirectly by injection into a neighboring well, one runs a second gamma-ray log. Differences between the two logs indicate depths in the well at which appreciable movement of the tagged fluid into or out of the formations has occurred.

To an oil man tracers fall into two classes, soluble and insoluble. The soluble ones include not only oil- and water-soluble (*4*) substances, but also gaseous compounds for tagging gases and vapors. The insoluble ones are particulates that are either totally insoluble in reservoir fluids or only partially soluble. Sometimes tracers are added to the fluid (water, acid, oil, etc.) at the surface; on the other hand sometimes they are released from a special holder built in the logging tool far down in the well. Figure 2 shows a typical field setup and the design of a small-diameter logging tool equipped with a holder for bottom-hole release.

Except for gaseous tracers, which require laboratory measurements, the tracer radioactivity is measured in the oil well with a tool on the end of an electrical cable. The gamma-ray detector is either a G-M counter or a scintillation crystal. An advantage of the G-M counter is that it will operate at high temperatures.

The sizes of tools for inserting the tracer and measuring its activity depend on the nature of the well. The most frequent uses of radiotracers are in producing wells, which are generally lined with two concentric steel pipes. The larger-diameter casing, which is cemented to the rock formation, is perforated at selected intervals to produce oil; the smaller-diameter tubing brings the oil to the surface. For measurements in a producing well the logging tool may have to be as small as $1\frac{7}{8}$ in. in diameter to pass through the tubing (*5*, *6*). If the well is under pressure, the tool is lowered through a lubricator, a device attached to the tubing top to prevent a blowout of the well. Many wells are not under pressure, and the tubing is removed before logging; then the logging-tool diameter is commonly $3\frac{5}{8}$ in.

Waterflooding

When a petroleum reservoir is first tapped, producing wells flow because of the natural pressure that exists in the reservoir. To stimulate production after this pressure is gone, water under pressure is put into one or more injection wells to increase oil (and water) flow at producing wells (Fig. 3). Injected water passes between wells through natural interstices in rock formations and both natural and man-made fractures. By adding gamma-emitting nuclides at selected times to the input water (*7*, *8*) one can derive several types of information:

Water input profiles that show the vertical distribution of injected water

Water-production profiles in producing wells that show vertical distribution of produced water

Rates of travel of water between wells

The flood pattern or horizontal distribution of injected water between wells under varying conditions of water input (varying locations of input wells and input pressures).

A water-input profile shows the vertical permeability distribution and hence whether injected water is entering the permeable formation of interest. Leaks in the iron casing and through the seat at the bottom of the casing show as radioactivity peaks on the log. If leaks exist, it may be necessary to repair them before continuing with the water-input profile. With the profile information in hand one takes remedial steps to redistribute injection water so as to increase production efficiency. One can determine an input profile with either a water-soluble tracer or a particulate tracer that filters out of the water on the formation face. A typical profile made with particulates (Fig. 4) agrees with permeability measured on cores from the well (*8*).

Analysis. Before starting a test, one would like to know what tracer concentration to use and when to expect the tracer at the producing well. But detailed predictions of field tracer results rarely appear in print because of the complexity of tracer losses in an underground reservoir. The usual approach in practice is to use idealized solutions and modify them to include any additional information available.

For this purpose there are graphical solutions of the basic fluid-flow equations for homogeneous reservoir conditions and a "five-spot" well pattern (a producing well in the center of a square with injection wells at the corners) (*9*). The solutions can be extended for use with any flooding pattern for which the pressure distribution can be determined. The only influence considered as contributing to tracer loss is water dilution in the reservoir. Other losses that actually occur include adsorption, ion exchange, hydrolysis, precipitation, diffusion and replacing of connate water (water present in the formation before the operation began) (*4*). Even with their shortcomings the idealized results are useful in estimating arrival time of injected water at the production well, selecting the proper radiotracer and

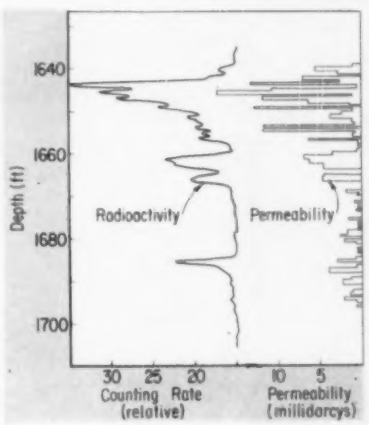


FIG. 4. PERMEABILITY PROFILE indicated by radiotracer (left) agrees well with core-sample measurements (right)

qualitatively interpreting relative arrival times at different wells.

Typical radiotracers used in practice are given in the table on this page.

In one system of making a water-injection profile a few millicuries of radiotracer is used in one of two streams pumped into the input well (Fig. 5). One of the streams is fed into a tube that extends to the bottom of the well, the other stream into the annulus between tubing and casing (*10*). The engineer locates the interface between the two fluids with a gamma-ray logging tool and follows it as flow rates are changed. The sum of the two rates is kept constant. For a given change in flow rates, the interface will move a distance that depends on permeability of the formation. If permeability is small, the interface may move a considerable distance. If there is a large fracture (or a casing-shoe leak), the interface may remain stationary.

Radiotracers Used in Producing-Well Operations

Operation and purpose	*Tracer*
Waterflooding	
to locate permeable, porous zones	I^{131}, Ir^{192} (1–2 mc) in soluble solution I^{131}, Co^{60} (1–2 mc) as insoluble particulates
to determine direction and rate of flow of injection water between wells	I^{131}, Ir^{192}, (60–100 mc); H^3 (3 curies)
to determine orientation of formation fractures (by gas injection prior to waterflooding)	Kr^{85} (15 mc/day for 12 weeks)
Cementing	
to locate top of cement	I^{131} (5 mc); Co^{60}, Ra (0.5–1 mc) mixed in cement slurry
to locate thief zones	I^{131} particulates
to locate cement and casing leaks	Ra (1 mc), Zr^{95}, Zn^{65}, Cs^{134} in water solution
Hydraulic fracturing	
to locate zones that have been fractured	I^{131} (10 mc impregnated in plastic beads); Fe^{59} (on surface of sand grains); Ir^{192} (10–30 mc)
Lost circulation	
to pinpoint formations stealing large quantities of drilling mud	I^{131} (5 mc in particulates), Ra (60 mc/ton of mud)
Salt-dome storage cavern	
to locate brine-oil interface	Co^{60} (as oil-soluble cobaltous napthenate), Sb^{124}-tagged triphenyl stilbene (6–20 mc)
Acidizing	
to control location of acid and hence restrict treatment to producible formations	I^{131} (0.5 mc per 1,000 gal of acid); Ir^{192} (10–30 mc); Zr^{95} oxalate; metallic Zn^{69}
Gas and liquid-propane injection	
to follow flow from injection well to producing wells	I^{131} (as ethyl iodide); C^{14} (20 mc), H^3 (1 curie as methane); Kr^{85} (0.3 curie)
to determine source of leakage from underground storage dome	Kr^{85} (1.5 curie)

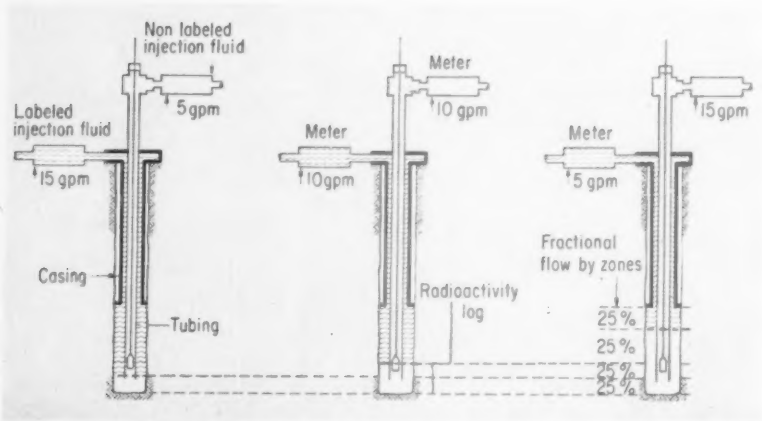


FIG. 5. BALANCE BETWEEN TWO FLOWS reveals permeability of formations when one flow is labeled and interface is followed with logging detector. Rates change while their sum is maintained constant

Tracers. A tracer commonly used for injection water is 8-day I^{131} stabilized to prevent air oxidation. If one wants to make a second set of input and producing profiles after remedial procedures, one uses a tracer that has both half-life and gamma-ray energy different from the original one. Thus both I^{131} and 74-day Ir^{192}, injected 26 hr apart, have been used in a single waterflooding operation (*11*). Pulse-height distribution and decay curves were used to identify each one. If one is to use this technique successfully, adsorption characteristics of the two tracers in the rock formation should be nearly the same.

When an insoluble tracer is used, the density of the particulates is matched to the density of the water at the depth and pressure of injection so that the particulates will just hover in the carrying fluid, neither falling to the bottom nor rising to the top of the well. This density matching has been shown to be essential for obtaining quantitative results (*5*). Permanent fixation of the radionuclide in the tracer particulate is also necessary. Particle sizes of 500–3,000 microns have been used. If the particles are too small, they can penetrate so far into some loose sands as to give an erroneous low radiation level opposite very permeable zones. I^{131} and Co^{60} are commonly used in insoluble forms.

Tritium. The natural concentration of tritium in rain and river water has greatly increased in the past several years because of hydrogen-bomb tests. The tritium content of recent water has been used as a tracer of input water in flooding operations in Wyoming (*12*). By tritium analysis of produced water one can tell when input water reaches producing wells. Tri-

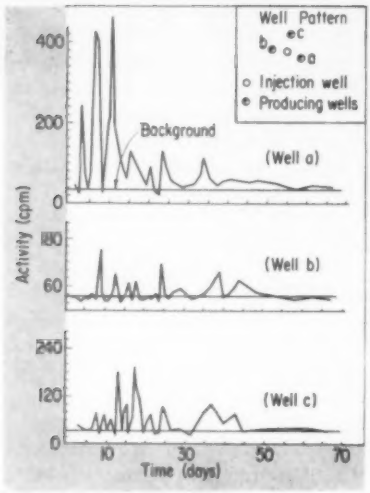


FIG. 6. TAGGED-WATER COUNTS at three production wells reveal flow rates and patterns when water goes into input well

tium has several advantages over other nuclides, including little adsorption on the rock surfaces, practically no radiation hazard (weak beta radiation and dilution by large volume of water) and a reasonably long half-life.

Tagging of injection water with added tritium has been successfully used in Russia to determine direction and flow rate of water from injection wells (*13, 14*). Samples of water taken successively after injection from producing wells surrounding injection wells were measured for tritium content by introducing hydrogen from dissociation of the water into a G-M counter. When it was necessary, electrolytic enrichment concentrated tritium by a factor of 7–10. Figure 6 shows the amounts of radioactivity measured at various times in waters from three wells surrounding an injection well. Total tritium activity was 3 curies.

Tritium-marked water was injected into a sandstone stratum in three equal portions of ~1 m^3 each at 2-hr intervals. Between each two portions about 20 m^3 of water were injected. This procedure gave sufficient concentration of tritium in the produced water for analysis without electrolytic enrichment. The tritium concentration dropped from 1 mc/liter at injection to an estimated 10^{-4} mc/liter at the producing wells. Distances from injection well to producing wells were (a) 115, (b) 80 and (c) 150 meters.

The three peaks of increased radioactivity on the curves can be attributed to the three waves of tracer injection into the stratum or to flow of water through the formation along three beds of different permeability; it is not possible to tell which of these two explanations is correct. Flow speeds in the three directions have marked differences. Advantages of this method of tagging injection water are that it is not necessary to stop production during the experiments and the weak beta radiation of tritium does not affect radioactive logging in the well.

Large-scale studies. Perhaps the largest water-injection tracer study has been in the Sacroc Unit, Kelly-Snyder Field, Texas (*15*). This is a joint operation involving 80 oil operators and 1,243 wells into a reef reservoir. Fifty-nine of these wells were surveyed in 30 days with particulate tracers in the input water. Tracer accumulated where porous zones were taking water. Since gamma-ray logs were run before and after adding tracer, increased radioactivity on the second log indicated porous zones. This information gave the thickness of the zones taking water in the various input wells and hence the volume of the input zones. A typical tracer was 1.5 mc of I^{131}.

What will be the world's largest unitized water flood, the huge 61,440-acre Spraberry Driver project in West Texas, has been approved (*16*) and initial water injections may begin in the first part of 1961. Directional orientation of fractures in the formation was determined by a radioactive-tracer technique so that engineers can take advantage of the fracture directions in planning waterflood operations (*17*). Kr^{85} was metered into natural gas to give a specific activity of 0.03 $\mu c/ft^3$ and injected at the rate of 500 ft^3/day for a total of 12 weeks into one injection well. Produced gas was monitored continuously at 12 production wells. Tracer was first detected at a well 1,884 ft from the injection site 64 days after tracer injection was started and at a second well 4,161 ft from the injection well 103 days after injection. At the other 10 wells no tracer was detected at any time. The generally northeasterly fracture line thus indicated agrees quite well with that predicted from core-orientation studies.

Oil-Water Contact

In both new and old oil wells location of oil and water-bearing portions of a fluid-saturated rock is fundamental to economical oil production. Position of an oil-water contact can be determined with activated solutions or chemical reagents that penetrate differently into oil-bearing and water-bearing portions. Naptha soap containing sodium salts of naphthenic acids has been used as a reagent of this sort in Russia (*18*). When the soap comes in contact with formation water, a metathetic (exchange) reaction forms insoluble calcium and magnesium napthenates, which seal the pores of the water-bearing bed and arrest penetration of fluid into that portion of the bed. After the well has been flooded with tagged solution, oil-bearing beds display a sharply increased gamma-ray intensity compared to water-bearing beds. In one of the wells of Fig. 7, gamma radiation intensity opposite the oil-bearing level is ten times as great as that at the lower, water-filled level.

Cementing

In most new wells temperature logs are accurate enough for locating cement since cement setting produces heat. New cementing materials that do not release heat on setting, however, make radiotracer surveys particularly valuable.

To locate cement one adds a tracer to the mix (*19*), enough to give an estimated reading ten times background after the cement has been squeezed behind the casing. On a gamma-ray log the cement top is indicated by a

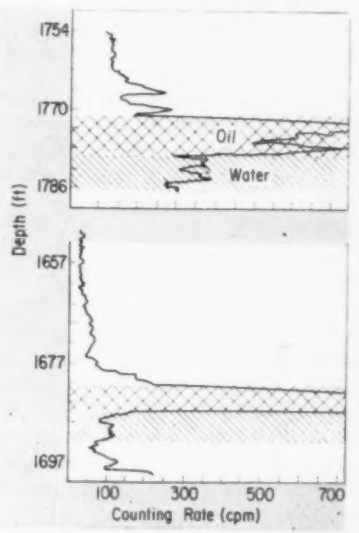


FIG. 7. SOAP TRACER seals water-bearing beds and penetrates only into oil-bearing strata. Large counting rate shows oil

drop in the radiation intensity to natural gamma-ray background. After the cementing has been completed, cement tops can be located for a period of 3–4 half-lives, which can be considerably longer than the interval in which temperature logs are practical.

Another accomplishment with cement tracing is location of thief zones (very permeable formations with large loss of cement). They can be identified with particulate tracers mixed through the entire cement mix.

Both water-soluble and particulate tracers have been used to locate cement tops and channeling (*1*). Radium has long been used for this purpose, but it leaves the hole permanently radioactive. Hence today a short-lived tracer such as I^{131} is generally used.

Leaks. To test effectiveness of a cement job, one uses a tracer in water injected into the formation through perforations in tubing and casing. Packers above and below the perforated zone restrict injected water to the zone of interest. After tracer has been injected, the well is flushed and a gamma-ray log is run. Radioactivity greater than the natural background at points above or below the perforated zone indicates leaks in the cement or casing (*20*).

Hydraulic Fracturing

To increase oil production, fluid can be pumped down a well under pressure to split the rock formation containing oil. Silica sand grains or other materials suspended in the fluid move into the fractures to hold them open after fracturing pressure has been removed. Fracturing exposes large volumes of oil-bearing rock for drainage along the fractures into the borehole. This process has successfully rejuvenated tens of thousands of old wells and increased production in numerous new wells.

Various radiotracers locate the zones affected by hydraulic fracturing (*21*). Injected sand can be permanently tagged or a separate particulate tracer can be added to the sand. One tagging method is to convert radioactive iron in chemical solution to iron oxide on the sand surface. A large quantity of tagged sand must be handled, but this sand has the advantage of being easy to blend uniformly into the bulk of fracture sand. A more commonly used tracer is I^{131} impregnated into beads made of plastic or some porous material of the same mesh size as the fracturing sand. The tagged beads are added to the last few hundred pounds of sand.

After fracturing has been completed, a gamma-ray log is run. If tagged particles have been deposited near the well bore, a radioactive high appears on the log to indicate the zones where fluid entered the formations. Figure 8 shows a fracturing operation with a radioactive tracer and gives actual field logs taken before and after fracturing.

Circulation Loss

In drilling a well, engineers use mud to lubricate the drilling bit and carry rock cuttings to the surface. Often when the composition of the mud has been changed by the addition of viscosity-control or weighting agents (commonly barites), the increased hydrostatic pressure causes one or more formations in the hole to break down and start accepting mud readily. Stealing of large quantities of mud by such permeable formations prevents adequate circulation to greater depth, and drilling ceases.

One can find zones of such lost circulation with a particulate tracer added to the drilling fluid either at the surface or downhole (*1*). Radioactive mud will enter the thief zone and produce a great concentration of particulate tracer at this depth; the zone can then be accurately located by a gamma-ray log.

This pinpointing of formations that break down and take mud allows economical use of plugging materials over the troublesome interval rather than over the entire section of open hole. Remedial treatments include a variety of time-setting clay or diesel-bentonite mixtures and batches of cement laden with pearlites, walnut hulls or other lost-circulation material to plug the thief zones, thereby restoring circulation of the mud to greater depths in the hole.

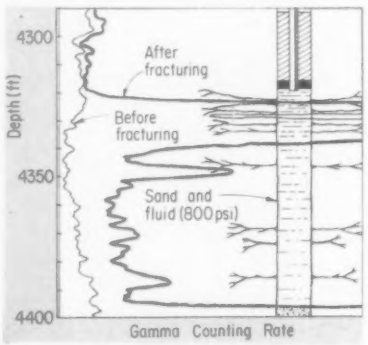


FIG. 8. FRACTURING OPERATION forces sand-bearing water into formations to release oil. Tracer follows fractures

Figure 9 shows a log made after pumping 55 bbl of radioactive mud into a 300-ft zone of lost circulation (*22*). Intense radioactivity at 8,030 to 8,050 and 8,180 to 8,190 ft, to a smaller extent from 8,200 to 8,245 ft and a sharp drop in gamma-ray intensity at 8,245 ft indicate thief zones at these depths. Corrective measures consisted of cementing with a special slow-set cement containing pearlite and cellophane strips. After treatment full circulation was restored, permitting drilling to greater depths.

Salt-Dome Interfaces

Underground caverns in salt domes are used to supply salt brine to chemical plants and store liquid petroleum gas (LPG). Both density measurements (*3*) and radioactive tracing (*23*) have been used to locate the hydrocarbon-brine interface. An oil-soluble solution of Co^{60}-napthenate and Sb^{124}-tagged triphenyl stilbene have been used with equal success. Six to 20 mc of radioactivity is used, the amount depending on estimated cavity diameter at the oil level and gamma-ray-detector sensitivity. Another technique is to use tagged beads of such a density that they float at the oil-brine interface.

Acidizing

In carbonate reservoirs engineers sometimes pump huge quantities of acid (as much as 30,000 gal of 15% hydrochloric acid) into the well to stimulate production. Injection of the acid is usually at a pressure sufficient to open and extend fractures into the rock through which the acid penetrates; pressure may be as great as 2,000 psi. The acid is pumped into the well through a tubing that ends near the bottom of the hole. The annulus between tubing and casing is filled with oil.

To avoid wasting acid on nonproducible formations, one must control accurately the position of the acid in the well. Hence radioactive tracers follow movement of the acid in the borehole and into formations (*1*). Tracer, soluble in acid but insoluble in oil, is released by remote control from the logging tool (Fig. 2) at ~100 ft

above the zone of interest. By running a log during the acidizing process, one can follow continuously the level of the acid in the well. The tracer in the acid in the tubing gives a rather high but steady background reading, but a much greater change of reading occurs at the interface of acid and oil in the annulus between tubing and casing. After completion of acidizing a gamma-ray log shows where the tracer (and hence the acid) entered the formation. If the acid did not enter at proper depth, remedial cementing is indicated. A typical tracer is I^{131} in quantities of 0.5 mc/1,000 gal of acid.

In Russia certain low-porosity (0.5%–2%) limestones of zero permeability yield large quantities of gas after treatment with hydrochloric acid under pressure to open up fractures. To see if the acid is entering the bed intended for treatment the acid is tagged with oxalate of Zr^{95} or metallic Zn^{69}. These nuclides distribute themselves well in the acid and are readily adsorbed in the rock right next to the walls of the well; thus they give large readings on a gamma-ray log after treatment.

A preliminary run is made with tagged water to reveal possible zones of penetration of acid. A few cubic meters of water marked with activity at the same level as the acid (0.8–1 mc/m^3) is injected at a pressure equal to the pressure of acid treatment. If the marked water has gone into a water-bearing bed, one must shut off this bed by cementing before beginning acid treatment of the gas-bearing bed (*24*).

Gas-Propane Injection

Conventional methods of producing crude oil generally leave in the depleted reservoirs 1–3 bbl of oil for every barrel produced. To improve oil recovery waterflooding has long been used. Gas can also be injected, and recently a new method has come into use: gas-driven liquid propane is injected into the reservoir (*25*). Dry natural gas, injected behind the propane, drives propane and oil to producing wells.

The location of gas entry into a formation has been determined by using I^{131} in ethyl iodide to obtain an injectivity profile (*26*). The technique is very similar to that used in water-injectivity-profile surveys (*10*). A radiotracer in one of two injection gas streams entering the well enables location of the interface between the two streams with a gamma-ray logging tool. Distribution of gas injection into the well is made by varying the rates of the two streams (combined gas input remains constant) and following the radioactive interface with a logging tool. The injectivity profile shows whether gas is entering the formation over the intended injection interval. If the profile is not as desired, one can perform remedial operations, followed by a second injectivity-profile survey.

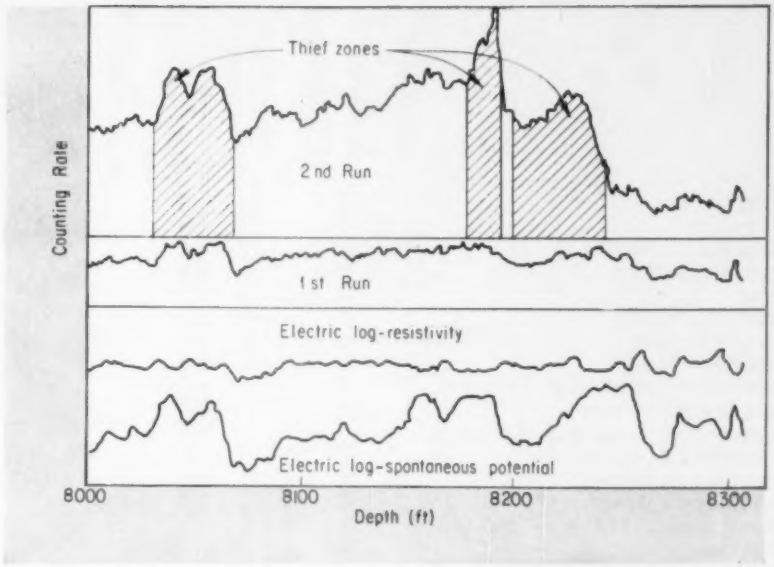


FIG. 9. CIRCULATION LOSS shows up as radioactivity peak after radioactive mud flows into well. Information is well correlated with similar findings of electrical logs

To follow gas from injection well to producing well, one adds a small quantity of radioactive gas to the pressure line of the input well at injection time (*27, 28*). Beta radiation of samples from output wells is measured in a gas counter. In addition to giving travel time for injected gas, appearance of radioactivity in producing wells is useful for determining flow pattern of produced gas.

Labels. In the Dalum Field of northwest Germany 20 mc of C^{14} in methane was used. Other tracers that have been used are Kr^{85}, tritium-tagged methane and gaseous tritium (*29, 30*). Krypton, being inert, has the advantage of not staying in the reservoir because of chemical reaction or absorption. In three different tests in one field 1 curie each of tritium and tritium-labeled methane and ~0.33 curie of Kr^{85} were injected with nearly the same results for elapsed time between injection and appearance of tracer at a production well (*29*).

A large-scale application of a short-lived tracer, 1.82-hr Ar^{41}, was determination of gas leakage from the Herscher natural-gas storage dome in Illinois (*31*). A total of 27 tests were carried out with more than 40 curies of Ar^{41} produced at nearby Argonne National Laboratory.

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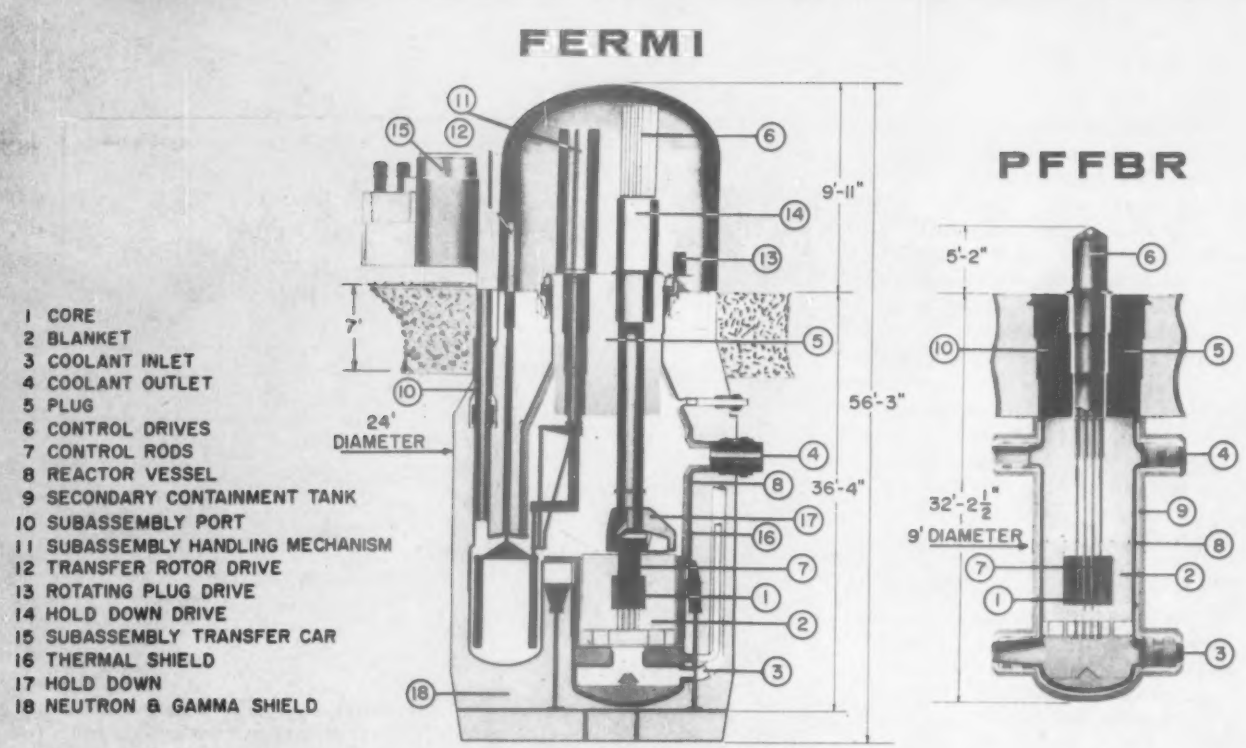


FIG. 1. REACTOR PRESSURE VESSEL is significantly smaller and less complicated in PFFBR after elimination of complicated Fermi fuel-handling mechanism and internal thermal shielding. New fuel handler (not shown) is simple single-arm device that fits into place of control-rod drive plug whenever reactor is shutdown for refueling. New refueling cycle is 6 months instead of 2 weeks for Fermi

From Fermi to PFFBR . . . Capital-Costs Reduced for Fast Breeders

A new fuel material, redesigned auxiliaries and cheaper shielding add up to a dramatic 50% reduction in the capital costs for the reactor part of a second-generation fast-breeder designed by the builders of Fermi

By JOHN G. YEVICK and ALFRED AMOROSI, *Atomic Power Development Associates, Inc., Detroit, Michigan*

POWER-REACTOR BUILDERS are convinced that present high capital costs for these plants will come down to more reasonable levels as the nuclear industry gains in design and operating experience. The fast-breeder program provides a graphic case study of how these cost reductions will come to pass for this particular reactor concept.

The basic designs for the EFFBR (Enrico Fermi Fast Breeder Reactor) and EBR-II (Experimental Breeder Reactor) were fixed early in 1955. About a year ago we completed a detailed design for an advanced fast-breeder plant, the PFFBR (Plutonium Fueled Fast Breeder Reactor), of the same power output as Fermi. The knowledge and experience gained in the intervening five years have made possible design changes that reduce the price of the reactor part of the PFFBR plant to *half* that in Fermi and trim the total plant cost by 35%.

The new knowledge has come in the form of technological advances, improved understanding of design requirements and the operation of prototype equipment and model tests. The technological improvements that have taken place include:

• Experimental results on higher-performance and higher-

burnup fuel materials such as PuO_2-UO_2

- Information on the irradiation stability of stainless steel at a flux of 10^{22} nvt and neutron energy of 100 kev
- Development of high-temperature shielding materials such as borated graphite, serpentine concrete and iron oxide
- Information on thermal transients and resultant thermal stresses that permits us to relax the requirements for thermal barriers.

An increased understanding of design from testing and from actual operation has come about in these areas:

- Fabrication, design and installation of the reactor vessel (Fig. 1), heat exchangers, pumps and other components
- Shielding, particularly neutron streaming in ducts
- Fuel handling, decay storage and fuel shipping
- Maintenance methods and procedures
- Reactor containment
- Core design
- Reactor-building ventilation and facilities for handling sodium, inert gases for waste disposal

Atomic Power Development Associates has incorporated these advances into two studies of its second-generation-fast-breeder system—the PFFBR (Fig. 2). The first study was for a plant of 300 Mw gross electrical output and the second for a plant of 150 Mw(e).

The 150-Mw(e) study can be compared directly with the Enrico Fermi plant [also a 150-Mw(e) installation] and thus provides a yardstick with which to measure progress in fast-breeder-reactor technology. It can also be compared with the average-size conventional steam plant now being installed in the U. S. A.

The studies have taken full advantage of the design and construction experience of the Enrico Fermi Atomic Power Plant, the Argonne National Laboratory EBR-II Plant and the British Dounreay plant.

Table 1 summarizes the projected Fermi and PFFBR costs. The capital charges for Fermi are well substantiated. The Fermi fuel-cycle costs assume an initial core loading of U-10-w/o-Mo. The Fermi research and development costs represent present estimates. The interest rates used to determine the annual charges are the average rates used in utility practice. The table shows costs for fuel-inventory charges of 10.33% (private ownership) and 4% (present AEC charges).

The impressive reduction anticipated for fuel-cycle costs will come about with the greater breeding ratio and fuel burnup possible with plutonium fuel. Proof must be obtained on a much larger scale, and proof of the operation of the complete fuel cycle must be substantiated. Work is now going on in this field. The EBR-II plant with its integrated pyrometallurgical reprocessing plant should demonstrate one attractive method of achieving a low fuel cycle cost. Oak Ridge National Lab as well as ANL are doing work on advanced fuel elements for fast reactors. Although some of this work is directed at the Fermi plant, results of it are directly applicable to the PFFBR plant and are expected to be completed in adequate time to incorporate into this plant. Other paths based on improved technology require research and development. Conceivably this work could be performed in time to provide fuel for the 1965 plant. However, if these programs are not carried out in time, fuel elements based on existing technology, such as UO_2 in stainless steel, could be used for the initial loading of the plant.

In this article, however, our concern is with the savings in capital cost. The 35% drop shown in this cost, while not as striking as the expected reduction in fuel cost, still represents a substantial step toward competitive power. Table 2 gives a more detailed comparison of the capital costs for the Fermi plant and the 150-Mw(e) PFFBR. The major cost reductions proposed by the study are in the reactor plant itself and come about as a result of the improvements in design detailed below. With these reductions the cost of the reactor plant is 30% of the total capital cost. The items "Indirect Construction Costs" and "Other Capital Costs," by comparison, now account for 36% of the total cost. The studies made no attempt to seek economies in these latter areas; such efforts might yield noteworthy savings. *(Continued)*

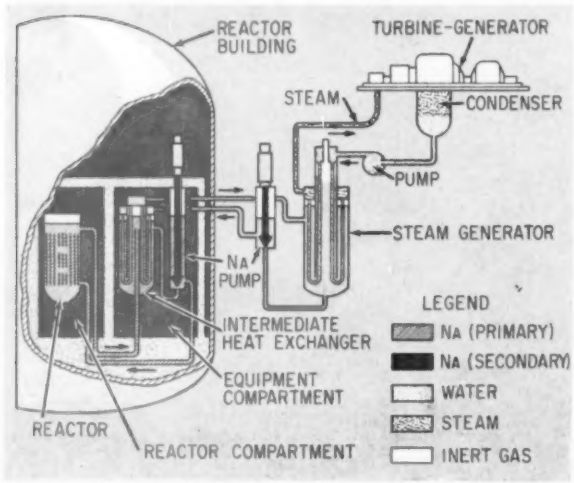


FIG. 2. FAST BREEDER FLOW DIAGRAM shows basic relationship of major components for both Fermi and PFFBR reactors. Intermediate heat exchanger transfers heat from radioactive primary loop to nonradioactive secondary coolant loop

TABLE 1—Projected Power Costs for Fermi and PFFBR

	*Fermi**	*PFFBR*†	
Gross output [Mw(e)]	150	150	300
Capital cost (10^6)	55.1	36.9	69.3
Capital cost [$/gross kw(e)]	367	246	231
Annual charges (mills/kwh)‡			
Capital	7.6	5.9	5.5
Fuel cycle	6.7	2.1	2.7
Operation and maintenance	1.6	1.4	0.8
Total (10.33% inv. charge)	15.9	9.4	9.0
Total (if 4% inv. charge)	14.5	9.0	8.6

* AEC Report TID-8518 Part III (figures for U-10 w/o Mo and 1.5 a/o burnup—adjusted to PFFBR basis).

† APDA-136 (March 1960) describes the 150-Mw(e) design and APDA-129 (April 1959) the 300-Mw(e) design. Latter updated to time of 150-Mw(e) study would show decrease in capital cost of at least $30/kw and fuel cost at least equal to the 150-Mw(e) study.

‡ Annual charges assume: 13.2% depreciable, 12.33% nondepreciable, 10.33% working capital; Pu credit, $12/gm; 70% plant factor; 1959 cost base.

Design Improvements

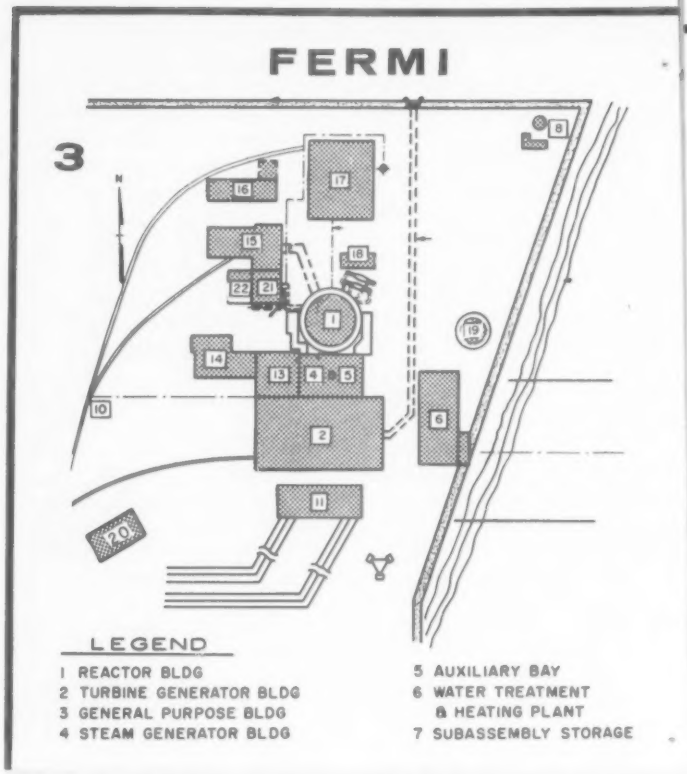
Plant layout. Figure 3 compares plot plans for Fermi and the 150-Mw(e) PFFBR. In PFFBR, health physics is combined with the office building. The sodium-service building and the sodium-service tunnel in Fermi have been eliminated by installing the sodium-service equipment in the reactor and steam-generator buildings. In PFFBR the steam-generator units are now isolated in separate buildings. The PFFBR inert-gas systems have been installed in the reactor building and steam-generator building. Since all of the fuel handling in PFFBR is performed within the reactor building, a small maintenance building replaces the building previously used both for storage of fuel during cooling and for maintenance.

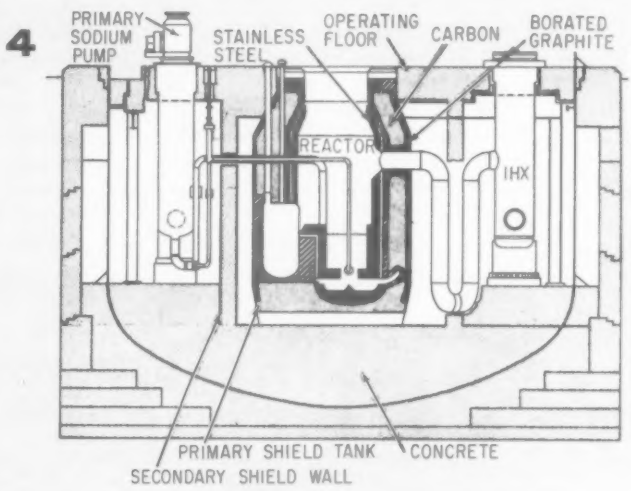
The ventilation building in Fermi has been eliminated. In PFFBR, freon-compressor units provide under-floor ventilation for the reactor building as well as above-floor cooling. In Fermi the under-floor atmosphere is cooled by a nitrogen-to-water heat-exchange system, which requires large duct systems between the reactor and ventilation buildings.

Reactor vessel, plug and refueling equipment. The reactor vessel for PFFBR (Fig. 1) shows a remarkable reduction in size over the Fermi vessel. The new vessel has no internal-radiation shielding and houses a thinner blanket. The 6-month refueling cycle (see below) permits a fixed plug with a central multipurpose handling mechanism to replace the rotating plug and cumbersome fuel-handling mechanism in Fermi. Consequently, a symmetrical cylindrical reactor vessel 8 ft in diam with a 0.5–0.75-in. wall takes the place in PFFBR of the 14-ft vessel of Fermi with 1.5–2.0 in. walls. Other cost-reducing design changes are the unit fuel-and-blanket support structure, elimination of the Fermi holddown in favor of a mechanical lock in the subassembly nozzle and reduction from 9 to 4 in the number of vessel nozzles.

The common central penetration in the reactor plug for control rods and refueling mechanism and elimination of the holddown make possible the fixed plug. Forming in lieu of machining the plug shell and bulk graphite shielding also reduces costs.

In the new refueling cycle, spent subassemblies are transferred from the core to positions in the blanket where they are allowed to decay in the reactor for 6 months. At the end of this period the spent fuel is simply removed by the multipurpose handling mechanism, canned on the spot and





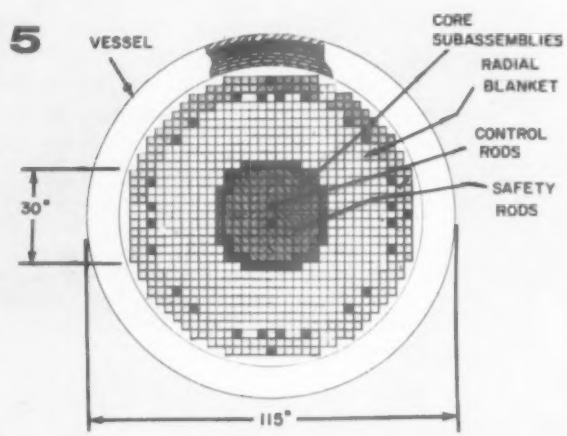
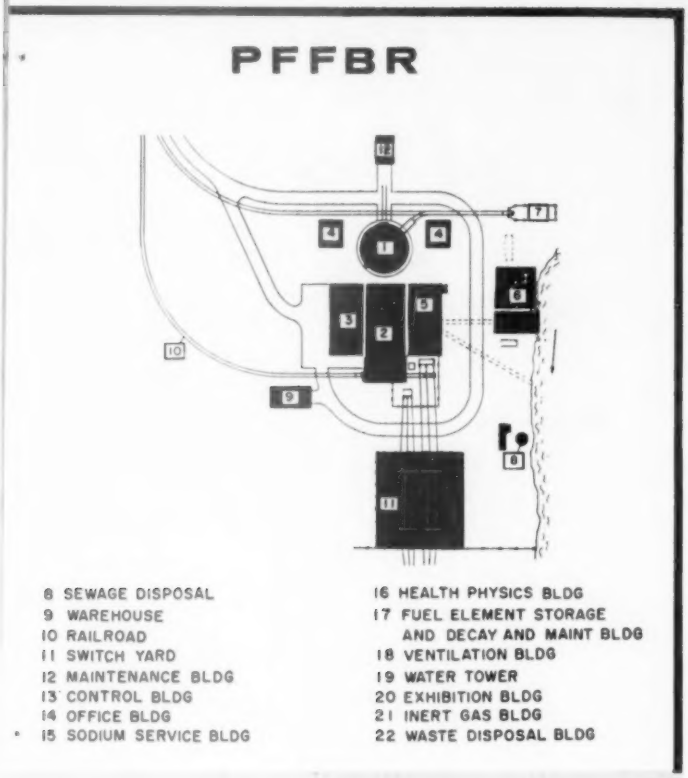
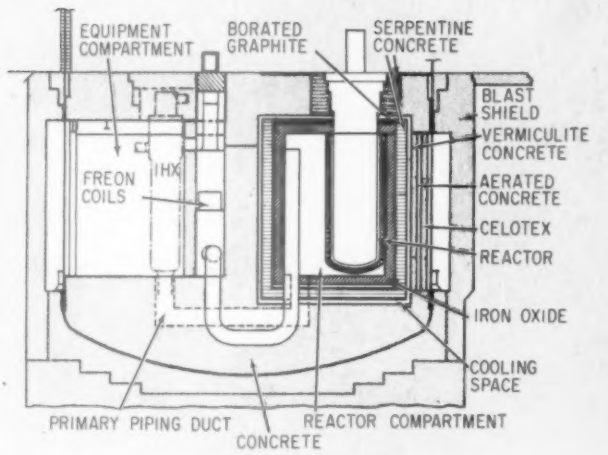


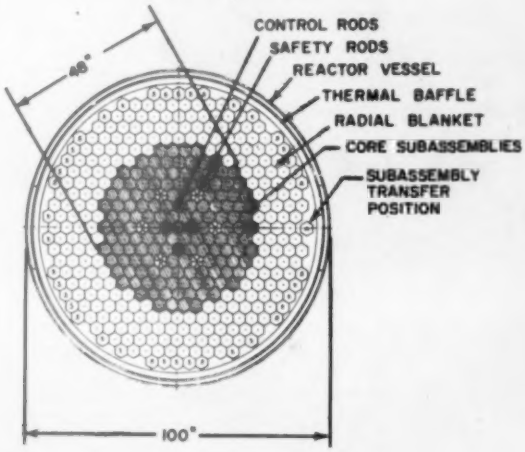
FIG. 3. PLANT LAYOUT shows reduction in number and sizes of buildings made possible by new system for handling spent fuel and APDA experience in building and operating other Fermi auxiliary equipment. Example: in PFFBR spent fuel is stored in outer blanket of core for 6 months' deccy period instead of in special building provided for Fermi plant

FIG. 4. SHIELD ARRANGEMENT in PFFBR replaces expensive stainless steel and borated graphite in Fermi with cheaper iron oxide and Serpentine cement as high-temperature shield materials and a variety of other specialized lower-temperature materials. New arrangement also makes equipment compartment more accessible for direct maintenance operations

FIG. 5. CORE LAYOUT shows larger active core in new design, which is price paid for switching to longer burnup oxide fuel. However optimization studies allowed thinner blanket, giving same over-all core diameter. Spent assemblies would be stored for six months' decay period in spaces marked *s*







shipped directly without further cleaning and storage. Other cost reductions result from the use of a single-subassembly transfer cask. The carrying out of these operations within the reactor building eliminates any need for an external subassembly cleaning, decay storage and shipping building.

Shielding

The new shield materials and shield arrangement in PFFBR allow easier access to the regions surrounding the pressure vessel and at the same time yield a savings in cost over the Fermi shield (see Fig. 4). The strategy in PFFBR has been to place an efficient high-temperature biological shield close in around the reactor vessel to reduce the radiation flux to tolerance levels in the adjacent equip-

TABLE 2—Capital Cost* Comparison for Fermi and PFFBR

	Total costs (10^6)		*Unit costs ($/gross kw)*	
	Fermi	*PFFBR†*	*Fermi*	*PFFBR†*
Direct Construction Costs				
Reactor building	2.265	1.872		
Reactor	4.535	1.563		
Fuel-handling facilities	3.455	1.400		
Heat-transport facilities—primary system	4.500	2.490		
Heat-transport facilities—secondary system	2.765	2.025		
Sodium-service facilities	1.300	0.330		
Inert-gas facilities	0.680	0.200		
Instrumentation and controls	1.410	1.025		
Health-physics facilities	0.300	0.180		
Auxiliary power system	0.800	0.645		
Maintenance facilities	1.075	0.485		
Waste-disposal facilities	0.435	0.050		
Total Reactor Plant	23.520	12.265	157	82
Turboelectric plant	10.500	10.045	70	67
Common plant facilities (site improvements and general services)	1.730	1.250	11	8
Total direct construction costs	35.570	23.560	238	157
Indirect Construction Costs				
Supervision and indirect construction	6.080	4.000	41	27
Engineering and drafting	3.060	1.950	20	13
Contingency	5.970	4.500	40	30
Total estimated construction costs	50.860	34.010	339	227
Other Capital Costs				
Interest during construction	3.050	2.040		
Cost of land	0.500	0.375		
Local taxes during construction	0.685	0.455		
Total other capital costs	4.235	2.870	28	19
TOTAL CAPITAL COST	55.095	36.880	367	246

* 1959 base.
† 150 Mw(e) plant.

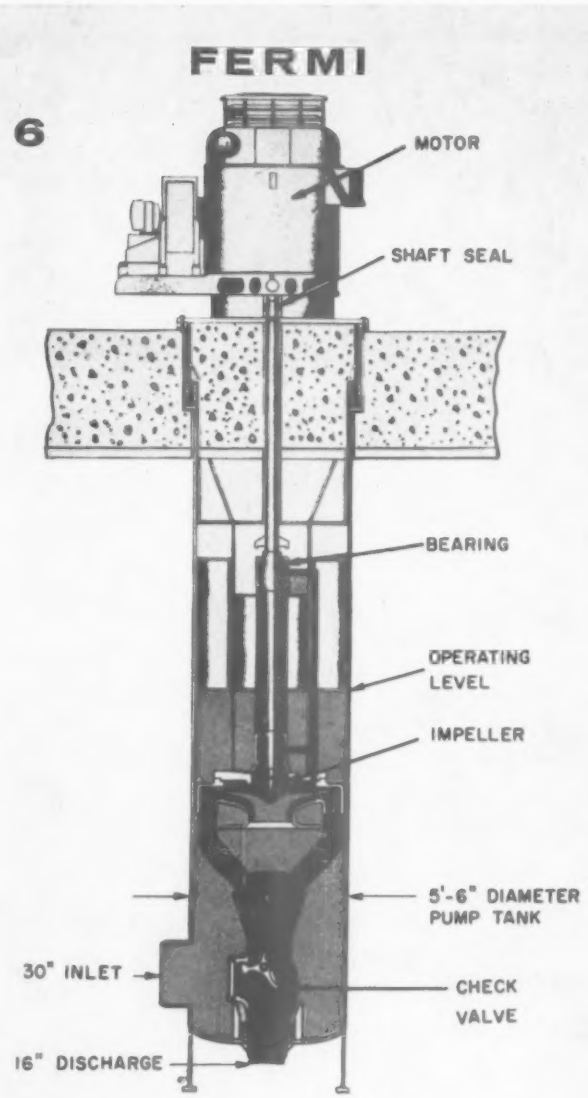
ment compartment and thus free those areas of neutron shielding material. As shown in Fig. 4, the radial part of the shield is located beyond the reactor sodium piping to prevent neutron streaming. The shielding is arranged in layers, the first of which is iron oxide. This layer acts both to absorb the energy carried by the gamma rays and to reduce the neutron energy. (It absorbs 95% of the energy in the gamma rays and neutrons.) The iron oxide layer replaces the much more expensive stainless-steel thermal shield in Fermi.

The second layer, a loose pack of Serpentine rock, serves as a high-temperature neutron shield. (Serpentine retains its high content of hydrogen up to 800° F.) This layer, to a large extent, replaces the borated graphite used in Fermi, again at a cost savings. The third layer, ordinary concrete, provides the remainder of the neutron and gamma attenuation.

The piping from the reactor runs into the floor below the reactor. Hence, neutrons streaming along the piping are absorbed in the concrete and ground below the reactor compartment. The length of the sodium piping and the number of bends are adjusted to keep the neutron level below biological tolerances at the point where the sodium pipes enter the equipment compartment.

A blast shield between the reactor and the containment building gives protection in the areas where the 7-ft-thick concrete wall is absent. This shield, plus the iron oxide, the serpentine and the concrete-shield walls, form a protective barrier between the containment building and the reactor vessel. The blast shield is a laminated of layers of absorbing material, held between steel plates that distribute the blast load over the entire layer of energy-absorbing material. The inner layer is vermiculite-aggregate concrete, the second layer is air-entrained concrete, and the third layer is Celotex. Each of these layers would absorb part of an explosive shock wave.

Fuel and fuel cycle. The 150-Mw(e) PFFBR will operate on recycle plutonium fuel, with only depleted uranium for makeup. Maximum inventory buildup is reached in three years. The reference value for average burnup is 50,000 Mwd/tonne of Pu plus U contained in the PuO_2-UO_2 fuel. Batch refueling occurs once each six months with twenty-three core subassemblies and fourteen blanket subassemblies removed each time. In contrast, the initial Fermi fuel of U-10-w/o-Mo is limited by radiation damage to average burnup of 15,000 Mwd/tonne of contained uranium with a batch refueling cycle every two weeks. The inventory is 1,579 kg of U^{235} in Fermi and 922 kg of Pu in PFFBR. This reduction comes chiefly through smaller out-of-core inventory needed with the lower throughput. The breeding ratio for PFFBR is 1.4 and 1.1 for



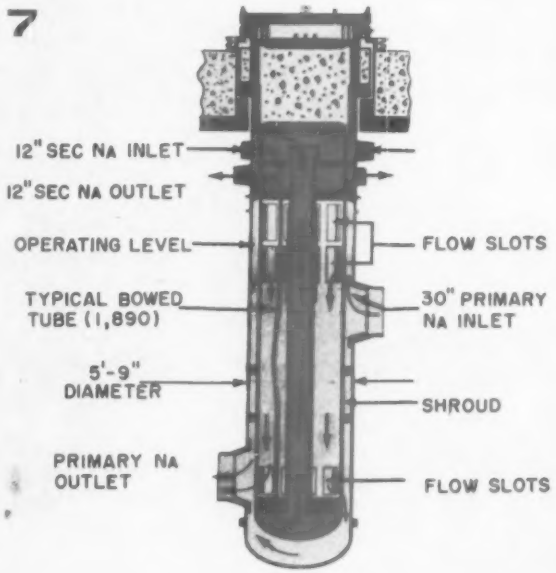
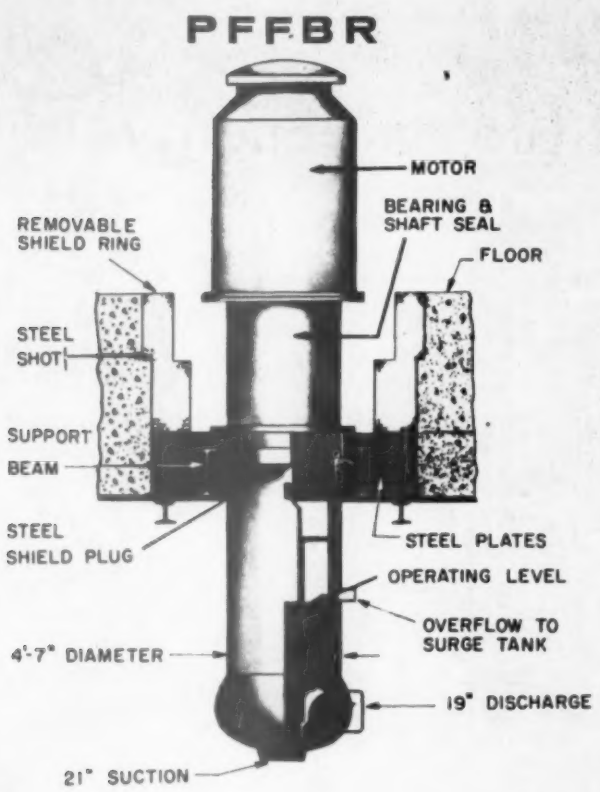
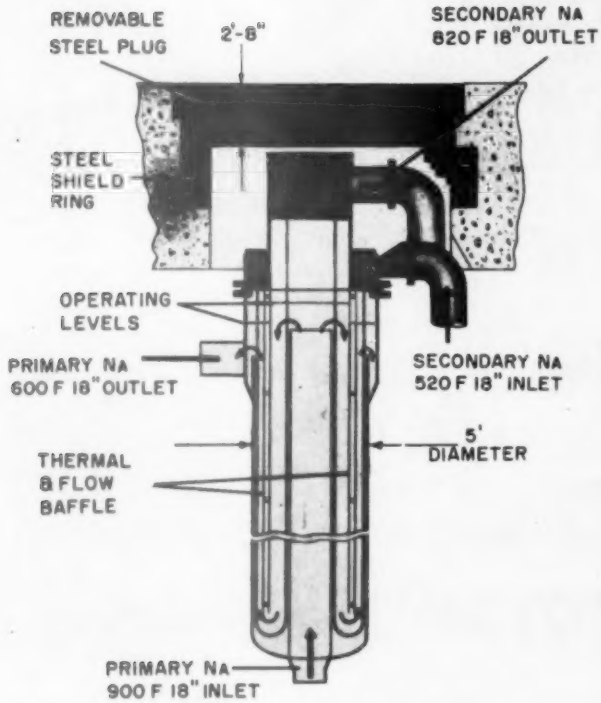


FIG. 6. PRIMARY SODIUM PUMP. Shorter shaft in PFFBR version reduces height and permits higher shaft speed (to 1,170 rpm) and smaller diameter impeller. PFFBR pump casing is made integral with shell of pump tank for easier removal. In new design, check valve (not shown) is located in separate housing elsewhere in system

FIG. 7. INTERMEDIATE HEAT EXCHANGER in PFFBR trades floating head for U-tube design in Fermi to ease thermal stress problems. In new arrangement separation of shielding from heat exchanger proper makes for easier access for maintenance





Fermi. The lower throughput and higher breeding ratio reduces the net fuel-cycle charge in PFFBR (see Table 1) by 4.5 mils kwh. Fuel costs for Fermi with a PFFBR loading, should, however, be as low as for PFFBR.

Figure 5 shows cross sections through the core and blanket of both reactor plants. The Fermi subassemblies are 2.7 in. square, designed ultimately to contain plate elements, while the PFFBR subassemblies are 3.65 in. hexagons, designed to contain rods. The PFFBR oxide fuel requires the core to be larger than in Fermi—4-ft diam by 4-ft high compared with 2.5-ft diam by 2.5-ft high for Fermi. Optimization of the depleted-uranium-oxide blanket in PFFBR has reduced its thickness to less than two-thirds that of depleted uranium alloy blanket in Fermi. Hence, the overall diameter of the core plus the blanket has remained about the same (see Fig. 5).

Sodium Pumps

In the primary-sodium pump for the PFFBR (Fig. 6) the pump casing is made integral with the shell of the pump tank, thus reducing the number of pieces that must be removed. The check valve is located in its own housing separate from the pump. The pump motor, set into a steel plug, allows for a shorter shaft, which in turn results in a 1,170-rpm pump and a smaller-diameter impeller.

Intermediate Heat Exchangers

The intermediate heat exchangers for the two reactors are compared in Fig. 7. The shielding for the heat exchangers for PFFBR is separate from the heat exchangers themselves, allowing for an improved heat-exchanger design. Bolted and seal-welded joints give access for maintenance and removal of the tube bundle. A U-tube unit replaces the floating head, eliminating some of the thermal barriers required for the Fermi heat exchanger. Introducing primary sodium through the central column reduces thermal stresses along the shell wall.

Steam Generator

The steam generator for the PFFBR, a once-through type with single-wall tubes, is very similar to the Fermi steam generator. However, because of a lack of data on erosion limits, the steam velocity in the Fermi generator was held to 60 ft/sec; experiments performed by APDA now have raised this limit in the PFFBR generator to 109 ft/sec. This means an increase in heat transfer coefficients in all sections; the largest increase, in the superheat section, was from 150 to 286 Btu/hr/ft/° F. In addition, the feedwater inlet temperature was decreased from 380° F in Fermi to 310° F in PFFBR which increased the log mean temperature difference and gave still higher total heat transfer per square foot. These improvements in high transfer rates together with an increase in the length to diameter ratio of the steam generator make possible a reduction in cost. Cost comparisons with the natural-circulation type of generator show that the once-through unit is now approximately one half as expensive.

* * *

The studies were conducted by APDA in conjunction with the following member companies: Allis-Chalmers, Babcock & Wilcox, Commonwealth Associates, Inc., Detroit Edison and United Engineers and Constructors, Inc. These organizations made available the full talents of the technical people in their design groups.

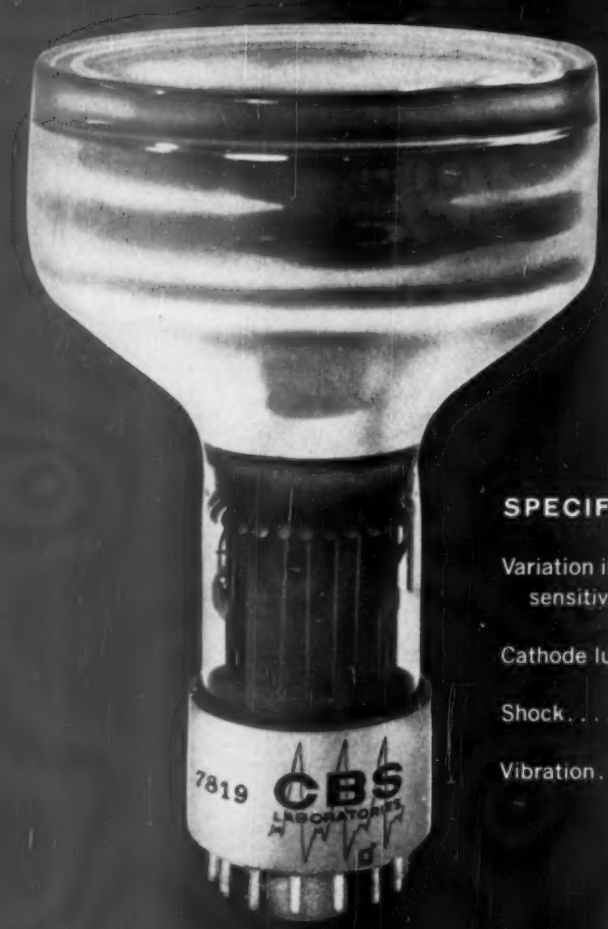
Beta Emitters by Half-Life and Energy

THIS TABLE helps to identify unknown beta emitters, whose half-lives and energies have been determined, and serves as a guide for selecting nuclides for applications requiring specific half-lives and energies. Detailed half-life and energy data are listed in "Table of the Radioactive Nuclides" [J. R. Stehn, NUCLEONICS **18**, No. 11, 186 (1960)].

Nuclides emitting betas of more than one energy are listed in each appropriate energy range. Bold-faced nuclides are positron emitters. Only nuclides having half-lives greater than 1 min. are listed.

A similar gamma chart was published in NUCLEONICS **18**, No. 11, 196 (1960).

	0-0.3 Mev	0.3-0.5 Mev	0.5-0.7 Mev	0.7-0.9 Mev	0.9-1.1 Mev	1.1-1.3 Mev	1.3-1.5 Mev	1.5-2.0 Mev	2-3 Mev	>3 Mev
1-10m		**In^{114}**		**Zr^{89m}** Ca^{49} Br^{84m} Ta^{178}	Ga^{74}	N^{13} Ne^{24} Nb^{94m} Te^{133}	Al^{29} Cr^{56} In^{118} Tl^{206} Tl^{207}	**O^{14} O^{15} F^{17} La^{136} Ne^{24}** Mg^{27} S^{37} Ca^{49} Ti^{51} Cu^{66} Ga^{74} Se^{83m} Br^{84m} Tc^{102} Ag^{108} Ag^{113m} In^{114} Ce^{145} Gd^{161} Ir^{197} Tl^{208} Tl^{209} Tl^{210} Re^{190} Re^{191} Os^{195} Hg^{203}	**K^{38} Fe^{53} Cu^{62} Ga^{64} Br^{78} Zr^{89m} Rh^{98} Sm^{143}** Np^{240m} Na^{25} Al^{28} Al^{29} Ti^{51} V^{52} V^{53} Cr^{55} Mn^{57} Fe^{61} Cu^{66} Zn^{71} Ga^{74} As^{79} Br^{85} Tc^{103} Ru^{107} Sn^{125m} Sb^{128} Te^{133} Cs^{128} La^{134} Pr^{140} Pm^{152} Pa^{234m} Ta^{186}	**O^{14} P^{30} Cu^{59} Zn^{61} Ga^{64} Ge^{65} Se^{71} Rb^{82} Tc^{92} Sb^{114} Sb^{118m} I^{122} Cs^{126}** Na^{25} S^{37} Cl^{40} Sc^{50} Se^{83m} Br^{84m} Kr^{89} Rb^{90} Rb^{91m} Nb^{99} Ag^{116} Xe^{137} Cs^{139}
10m-1h	**Tc^{96m} Ho^{160}** Am^{244}	**Re^{177}** Se^{83} Sb^{126} Cs^{130}	**Ho^{160}** In^{112} In^{116m} Ce^{146}	**Br^{80}** Co^{62} Zn^{69} In^{116m} Np^{240}	Cl^{38} Re^{180} Cl^{38} Se^{83} Te^{101} In^{116m} Te^{129} Ho^{164} Pb^{214}	Ag^{103} Mo^{102} Rh^{107} Sn^{123} Fr^{222} Ra^{227} Ra^{230} Th^{233} U^{239}	**Cl^{34m} Cr^{49} As^{70} Ag^{106} Rh^{81m} In^{108} Sb^{116m} Sb^{116} K^{44} Br^{80}** Se^{81} Tc^{101} Te^{129} I^{134} Sm^{155} Au^{201} Pb^{211} Bi^{213} Pa^{235} Pa^{237} Am^{244} Am^{246}	**V^{47} Cr^{49} Ge^{67} Se^{73m} Pd^{99} Cd^{105} Ag^{106} In^{107} Sn^{109} Sn^{111} In^{112} Sb^{115} Sb^{120} Cs^{130} Pr^{136} Cl^{39}** Sc^{49} Co^{60m} Ga^{70} Br^{80} Se^{83} Rb^{88} Cd^{117} Sb^{126} Te^{131} Nd^{151} Sm^{155} Ta^{185} Pt^{199} Am^{246}	**Cl^{34m}** Mn^{51} **Mn^{52m} Cu^{60} Zn^{63} Ga^{65} Ge^{67}** As^{69} As^{70} **Tc^{94} Ag^{104m} Sb^{116} Xe^{121}** Cs^{125} **Pr^{135} Nd^{138} Pm^{141} Eu^{144} Eu^{145} Ho^{160}** Cl^{38} Cl^{39} Co^{62} Br^{84} Rb^{89} Rb^{91} Mo^{101} Tc^{104} Pd^{111} Ag^{115} In^{119} I^{128} Te^{131m} I^{134} Xe^{138} Ba^{141} Pr^{144} Pr^{146} Eu^{158} Au^{200} Pa^{237} Am^{246}	**Cu^{60} Ge^{67} Br^{74} Mo^{91} In^{108} Ce^{131} Re^{178}** Cl^{38} Cl^{39} K^{44} Br^{84} Rb^{88} Rb^{89} Y^{94} Cs^{138} Ba^{142} Pr^{146} Bi^{214}
1-10h		**Cd^{107}** Cs^{134m} Pu^{243}	**F^{18} Zn^{62} Tc^{93} Pd^{101} Cs^{127}** Ni^{65} Kr^{88} Sr^{92} Rb^{106} Xe^{135} Ta^{180m} Au^{200} Pb^{209} Pu^{243}	**Sc^{43} Fe^{52} Rb^{82m} Tc^{93} Rh^{99m}** In^{109} **Eu^{152m}** Mn^{56} Ge^{78} Kr^{85m} In^{115m} In^{117} Te^{127} Sm^{156} Am^{245} Cm^{249} Bk^{250}	**Ti^{45} Rb^{81} Cs^{127} Pr^{139} Ta^{178}** S^{38} Mn^{56} Ni^{65} Ge^{75} Br^{83} Sr^{91} Cd^{117} Sb^{128} Xe^{135} Ho^{167} Er^{171}	**Sc^{43} Cu^{61} Ge^{66} Se^{73}** Mo^{90} Ru^{95} La^{133} Ce^{133} Er^{161} Pa^{207} Ar^{41} Co^{61} Ga^{73} Ge^{75} Kr^{87} Sr^{91} Y^{92} Nb^{97} Ru^{105} I^{132} Te^{133m} Dy^{165} Lu^{176m} Ta^{184} Hg^{192} Ir^{195} Ac^{228} Pa^{234}	**Sc^{44} Xe^{123} La^{131} Pr^{138}** Si^{31} Zn^{71m} Sr^{92} I^{135} Nd^{149} Yb^{177} Hf^{183}	**Ge^{66} Ga^{68} Se^{73} Br^{75} Kr^{77} Y^{82} Y^{84} Ba^{129} La^{131} Pr^{137} Ir^{190}** In^{117m} Sb^{129} I^{132} Pr^{145} Nd^{149} Pm^{150} Eu^{152m}	**Zr^{87} Nb^{89} In^{110} Te^{117} Yb^{165} Tm^{166} Hf^{169} Au^{192} Pb^{199}** S^{38} Ar^{41} Mn^{56} Ni^{65} Kr^{88} Y^{92} Ag^{113} I^{132} Te^{133m} Ba^{139} La^{141} Pm^{150} Ir^{195} Bi^{212}	**Ga^{66} I^{120} La^{132}** As^{78} Kr^{87} Y^{92} Ag^{112} La^{142}
10h-1d	Pd^{112}	Mg^{28} Nb^{96} Sn^{121} Pt^{197} Pb^{212} U^{240}	**Cu^{64}** Cu^{64} Nb^{96} I^{130} Pr^{142} Eu^{159} Pt^{197} Pb^{212} Np^{236m} Am^{242m} Bk^{248}	Co^{55} Pd^{109} Eu^{150} Eu^{157} Eu^{159}	**Y^{86} Hg^{193m}** I^{130}		**Nb^{90} Bi^{203}** Na^{24} Ge^{77} I^{133}	**Co^{55} Y^{86} Re^{180} Ir^{186}** **Re^{180}** Zr^{97} Eu^{157} Re^{188} Ir^{194}	Rh^{100} Th^{154} K^{42} Ge^{77} Y^{92} Pr^{142} Re^{188} Ir^{194}	Br^{76} Xe^{123} K^{42}
1-10d	Ni^{66} Zn^{72} Rh^{105} I^{131} Te^{132} Dy^{166} Au^{196} Au^{198} Au^{199} Th^{231} Pa^{232} U^{237} Es^{254}	**Br^{77}** Sc^{47} Cu^{67} Br^{82} Mo^{99} Te^{131m} Xe^{133} Er^{169} Yb^{175} Lu^{177} Au^{199}	**Mn^{52} Ge^{69} Kr^{79} Y^{87} Sb^{122}** Ca^{47} Sc^{47} Sc^{48} Cu^{67} As^{77} Rh^{105} Cd^{115} Te^{131m} I^{131} Sm^{153} Tb^{161} Ta^{183} W^{187}	**Ni^{57} As^{71} Zr^{89} Np^{234}** Ag^{111} Sb^{126} I^{131} Sm^{153} Np^{239}	Ag^{111} Ce^{143} Pm^{151} Re^{184} Au^{198} Es^{254}	**Ge^{69}** Sr^{83} Mo^{99} Cd^{115} Os^{193} Bi^{210m} Ac^{226} Np^{238}	**Au^{194} Tl^{200}** Sb^{122} Sb^{127} Ce^{143} W^{187} Au^{198}	**Ir^{188}** Ca^{47} Zn^{72} Sb^{122} Ho^{166} Tm^{172}	As^{72} I^{124} **Lu^{170}** As^{76} Y^{90} Sn^{125} Te^{131m} La^{140} Pm^{148}	As^{72}
10-100d	**Tc^{93m}** P^{33} S^{35} Fe^{59} Nb^{95} Ru^{103} Sb^{124} Os^{191} Hg^{203} Pa^{233} Th^{234} Pu^{246} Cf^{253}	**Co^{58} Pm^{145}** Sc^{46} Fe^{59} Zr^{95} I^{126} Cs^{136} Ce^{141} Nd^{147} **Hf^{181}** W^{185} Ra^{225} Pa^{230} Pu^{246}	**V^{48} Tc^{95m}** Rb^{86} Cd^{115m} Sb^{124} Cs^{136} Ce^{141} Tb^{160} Ir^{192} Pa^{233}	**Rb^{84}** Zr^{95} Nd^{147} Pm^{149}	As^{74} **Rh^{99}** **Bi^{205}** Rb^{84} Nb^{95} Rh^{99} Ba^{140} Pr^{143} Pm^{149}		**Co^{56}** Fe^{59} As^{74} Sr^{89}	**Ag^{74} Rb^{84}** P^{32} Rb^{86} Y^{91} Cd^{115m}	Sb^{124} Pm^{148} Eu^{156}	
100d-1y	Ca^{45} Ru^{106} Ag^{110m} Sb^{125} Bk^{249}	**Zn^{65}** Ag^{110m} **Y^{88}** Ag^{110m} Sb^{125} Ce^{144}	Sb^{125} Ta^{182}	Tm^{170}	Tm^{170}	Rh^{102} Rh^{102}	Sn^{123}			
1-10y	Cs^{134} Pm^{147} Eu^{155} Tm^{171} Ra^{228}	Co^{60} Sn^{121m}	**Na^{22}** Cs^{134} Pm^{146}	Cs^{134} Tl^{204}			Co^{60} Cs^{134}			
>10y	**Ho^{166m}** H^{3} C^{14} Si^{32} Ni^{63} Se^{79} Kr^{85} Rb^{87} Zr^{93} Tc^{98} Tc^{99} I^{129} Cs^{135} La^{138} Sm^{151} Eu^{154} Re^{187} Ac^{227} Pu^{241}	Nb^{94} Lu^{176}	**Be^{10}** Ar^{39} Kr^{85} Sr^{90} Cd^{113m} In^{115} Cs^{137} Am^{242}	**Eu^{152}** Cl^{36}		Al^{26} Cs^{137}	K^{40} Eu^{152}	Eu^{154}		Pu^{241}



SPECIFICATIONS:

Variation in cathode luminous sensitivity over entire cathode . . . . . ± 20%

Cathode luminous sensitivity . . . . . 70 ua/lumen

Shock . . . . . 40 g, 11 ms. duration

Vibration . . . . . 10 g, 25-2,000 cycles

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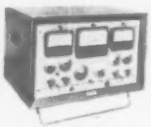

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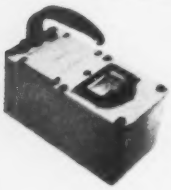

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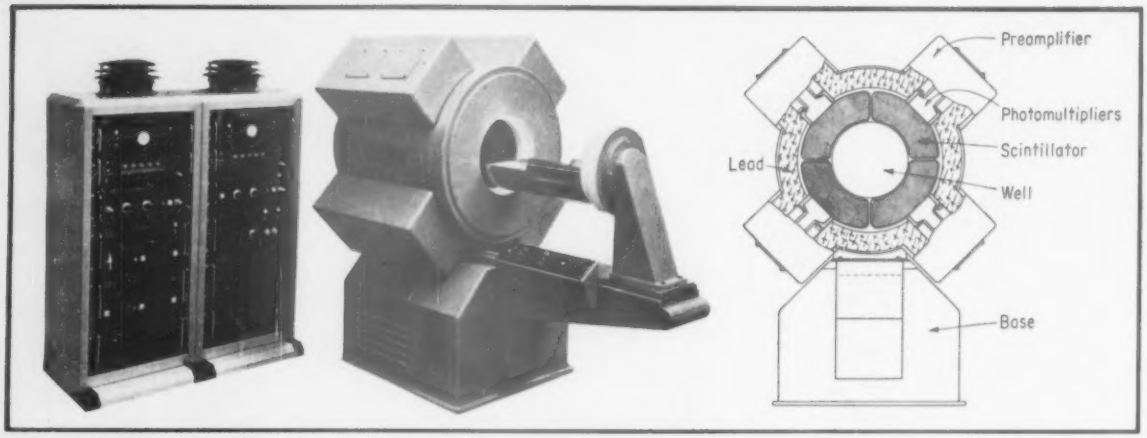


FIG. 1. COUNTER includes motor-driven cradle that holds samples and transports them into counting position. Electronics on the left record the counts. Counter cross section on right shows four scintillators, each viewed by two photomultipliers

K^{40} Gammas Give Estimate of Lean Meat Content

By DEREK H. PRINGLE, *Nuclear Enterprises Ltd., Edinburgh, Scotland*
and ROMAN KULWICH, *U. S. Department of Agriculture, Beltsville, Maryland*

In hams, as in humans, K^{40} gamma activity is related to the amount of lean meat (*1–3*). Therefore since gamma ray measurements provide an objective, nondestructive method for estimating lean content, this method may make marketing operations more effective than they are now provided the error of the estimate is sufficiently small. Before this process can be applied to marketing, however, further research must be done to determine just how closely K^{40} measurements are related to lean content. Measurements of large numbers of samples must be made to find out how K^{40} activity varies in different muscles and different animals. We are now using the large plastic scintillation counter that is shown in Fig. 1 for this purpose.

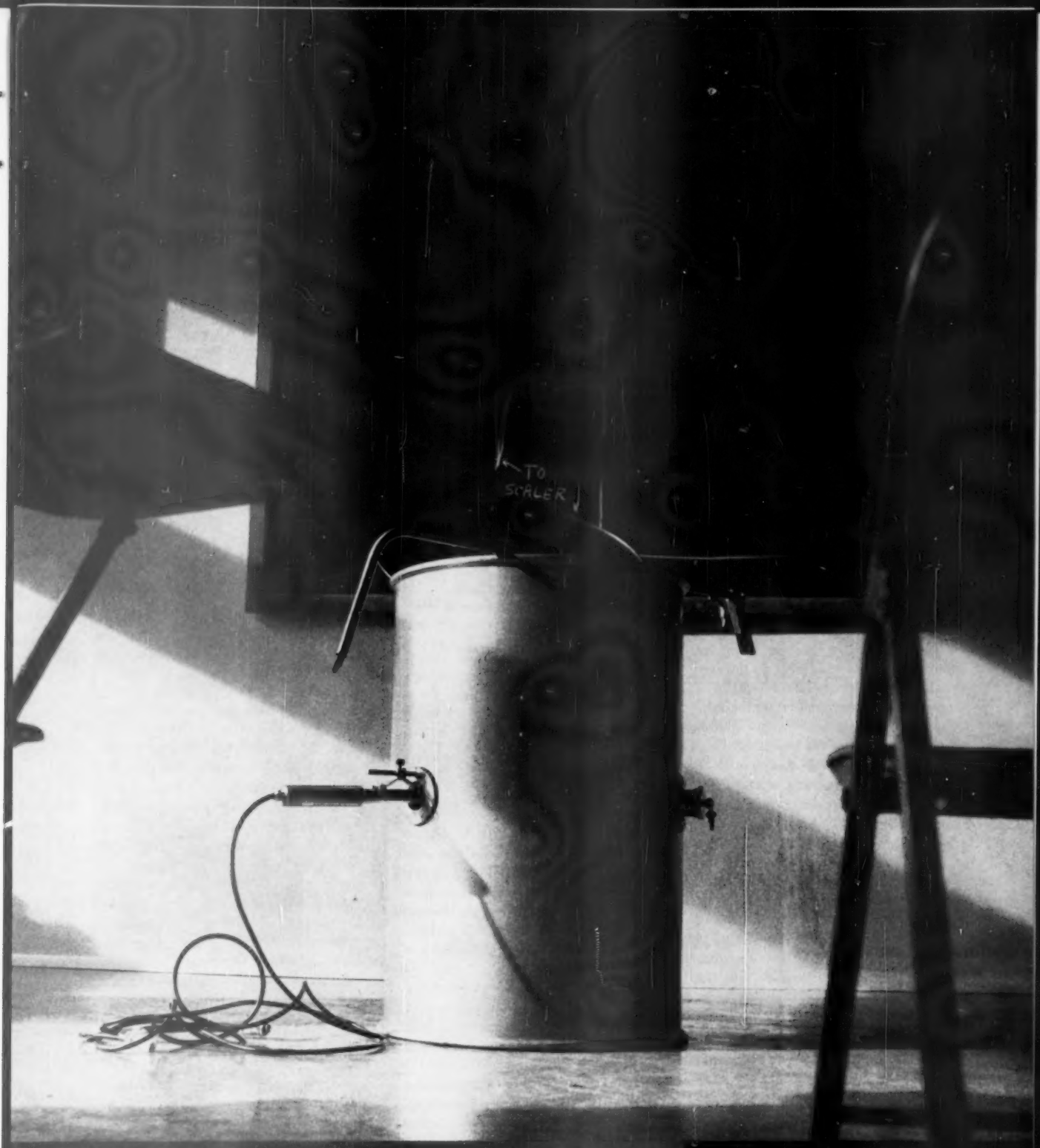
Our counter, which can measure meat samples weighing as much as 80-lb, contains four plastic scintillators in a 4π geometry. The scintillators are viewed by eight photomultipliers. They have sufficient resolution to separate naturally occurring K^{40} gamma activity (1.46 Mev) from Cs^{137} (0.661 Mev) fallout activity. These two activities are separated and then recorded simultaneously in two channels, one (~1–2.2 Mev) for K^{40} and one (~0.4–1 Mev) for Cs^{137}. The Cs^{137} is counted separately to determine whether a relationship exists between its abundance and the lean and fat content. Knowledge of the amount of Cs^{137} is also important for public health authorities.

Although we have made few experimental observations so far, it is quite evident from our results that there is a nearly linear relation between lean content (from a nitrogen estimation) in 50–60-lb samples of ham lean and fat and the K^{40} count (Table 1).

TABLE 1—K^{40} Measurements of Ham Lean and Fat

Sample	*Weight (lb)*	*K^{40} (cpm/lb) counting rate*	*Chemical analysis*		
			*Water (%)**	*Fat (%)**	*Lean (%)*†*
100% lean	59.50	44.1 ± 0.6	73.3	5.9	91.8
55% lean	51.00	24.2 ± 0.7	43.5	45.6	52.3
50% lean	58.13	22.5 ± 0.5	39.7	49.5	50.0
45% lean	61.13	21.1 ± 0.5	36.8	53.8	46.9
100% fat	57.56	0.4 ± 0.5	6.1	92.3	7.3
Fat jacket‡	47.31	22.7 ± 0.6	41.3	47.7	53.7
Fat and lean§	58.81	22.5 ± 0.5	42.0	47.1	52.2

* These percentages are by weight. Fat and lean should add up to 100%. They fail to do so only because of experimental error.
† Estimate from nitrogen measurement.
‡ Roll of lean surrounded by roll of fat.
§ Roll of lean end-on to roll of fat.



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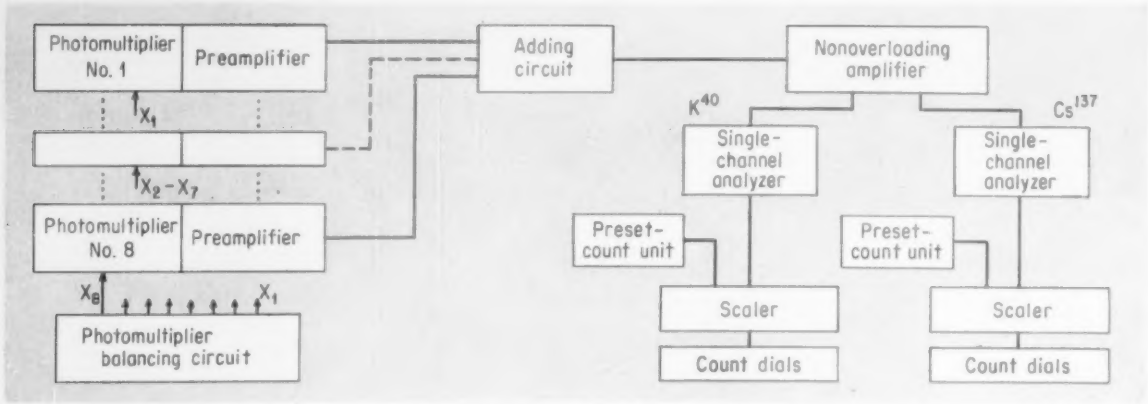

FIG. 2. CIRCUIT adds signals from photomultipliers, separates K^{40} and Cs^{137} signals and records them in two separate channels

Furthermore the results from the third, sixth and seventh samples shown in the table indicate that the geometrical configuration of lean and fat meat does not greatly affect the counting rate. The increase in counting rate with the increase in the per cent of lean content is ~0.5 cpm/%/lb.

Counter Design

In our counter, signals from the four scintillator quadrants go through cathode-follower preamplifiers to a circuit that combines their counts, then to two single-channel pulse-height analyzers that separate the K^{40} and Cs^{137} signals and finally to two sets of recording dials. The counter is designated by Nuclear Enterprises as its NE 8105* low-level counting facility (*4*).

Scintillator. To avoid toxicity and fire hazards associated with liquid scintillators as well as the need for rather complicated containers and liquid seals we made a scintillator in four quadrant sections, using a commercial scintillating plastic (Nuclear Enterprises NE 102*). This scintillator is ~24 in. long and has an outer diameter of 24 in. and an inner diameter of 14 in. The scintillators are sprayed with a reflective coating everywhere except where viewed by the photomultipliers. Therefore there is no optical coupling between the individual scintillator quadrants in the instrument.

Photomultipliers. To view the scintillators we selected eight 5-in.-diameter EMI 9530A* photomultipliers. Each of these high-resolution tubes has its own cathode-follower preamplifier. Energy resolution and pulse height improve as the number of photomultipliers increase; there must be a compromise, however, between these factors and the cost, installation and maintenance difficulties of the photomultipliers.

Light reflector. Phosphor-wall reflectivity in annular counters is important in determining what fraction of the emitted light finally reaches the photocathodes (*5, 6*). In our design the ratio of the fraction of the light that reaches the photocathodes to the fraction of the surface viewed by the photomultipliers is ~4%. We have found that a sprayed layer of alpha-alumina powder with a suitable binder and plasticizer is the most efficient reflector.

Shielding. To reduce background to a low level, the scintillator is completely surrounded by at least 3½ in. of aged lead (with very low RaD activity). A lead-filled door attached to the motor-driven stainless-steel cradle seals the entrance to the well after sample is inserted.

Circuit. The signals from the eight photomultipliers go by way of cathode-follower preamplifiers to an adding circuit in the base of the detector unit (Fig. 2). Here the signals from each pair of photomultipliers that view a single scintillator quadrant are combined into a single pulse and the pulses from all of the quadrants are combined into a single pulse train going to the control unit.

In the control unit the rest of the electronics is located. A nonoverloading linear amplifier (Nuclear Enterprises NE 5202,* gain of 50,000) feeds into two selector-scaler channels (Nuclear Enterprises NE 5102* and NE 5103*); the upper channel accepts ~1–2.2 Mev to count K^{40} gamma rays and the lower ~0.4–1 Mev to count Cs^{137} gammas. Preset-count units trigger the two scalers, and the sample activities are determined simultaneously on the two channels. There is, however,

Characteristics of the Instrument

Integral background (>150 kev) ~16,000 cpm

Counting rates and times with 76-gm KCl source

K^{40} channel rate ~43 cpm/gm of K^{40}

(Disintegration rate of K^{40} is 194 dpm/gm.)

Background-plus-sample time for 10^5 counts 14.59 min

Background alone, time for 10^5 counts 19.37 min

Standard deviation, K^{40} net counting rate 1.6%

TABLE 2—Counting Efficiency vs. Weight

Sample weight (lb)	*Content*	*Counting efficiency (%)*
0.71	pure KCl	22.0
1.00		19.0
4.2	1 lb KCl; remainder granulated sugar	17.5
14.0		15.4
20.0		14.8
28.0		14.2
36.0		14.0
59.0		12.5

* Mention of specific instruments or trade names is made for identification purposes only and does not imply any endorsement by the U. S. Government.

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Estimating Lean Meat

This article starts on page 74

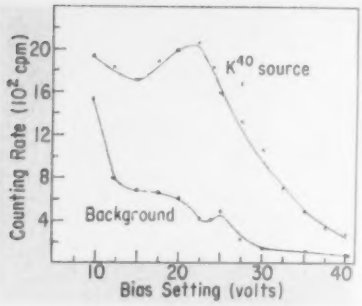

FIG. 3. DIFFERENTIAL SPECTRA for K^{40} source and for background

some spillover of K^{40} and Cs^{137} gammas from one channel to the other. When both Cs^{137} and K^{40} sources have equivalent activities, we may select upper-channel settings in such a way that the contribution of Cs^{137} is less than 1% of the total net K^{40} count. K^{40} counting efficiency can be increased by widening the upper channel; however, the Cs^{137} contribution then increases.

Although the pulse-height spectrum obtained from these gamma photons is produced by multiple Compton interactions, our large plastic scintillators give reasonable resolutions (*6–8*).

Performance

To get the best possible resolution of the total-absorption peak produced by multiple Compton scattering, one must obtain the spectral response from each photomultiplier (*9*). This can be done by setting the voltage on each of the tubes with the potentiometers of our photomultiplier-balancing circuit until the pulse height from each of the tubes becomes the same. The complete voltage range covered by the coarse stepped control, ~400 volts, is adequate to cover the variations in the characteristics of each tube as well as variations in dynode resistors and light-collection efficiency of each phosphor segment. It is best to carry out the balancing by measuring the counting rate in each channel in an energy interval on the rapidly falling edge of the Compton distribution.

For the balancing measurements we use a cardboard jig to place a cardboard container with 1 kg of KCl in the center of the counter. After setting the high-voltage supply at 1,250 volts and the amplifier gain at 12,500, we adjust coarse controls so that the integral counting rate in each tube above 0.47 Mev (bias 10 volts) for the sample plus background is ~6,000 cpm. Then we adjust the fine controls to give ~80 cpm in 5-min counts on each photomultiplier with a pulse height of 1.4 Mev (30 volts) and a window width of ~0.12 Mev (1 volt). After this we switch on all eight photomultipliers and measure the differential spectrum, first with source plus background and then with background alone (Fig. 3).

The resolution is ~27% (half width at half maximum). Although this could be improved by using additional photomultipliers, we get an adequate separation of K^{40} and Cs^{137} activities with our instrument.

Typical characteristics of our instrument are shown in the box on Page 76. Table 2 shows the effect of sample weight on counting efficiency in the K^{40} channel produced by self-absorption. To estimate the effect of the position of the sample within the detector, we made a series of measurements with the 1-kg sample in a cardboard cylinder (3¾-in. dia., 9 in. long). The lowest efficiency, with the cylinder at the extreme front of the detector, was ~70% of the counting efficiency at the center. Over a length of 18 in. in the well the counting efficiency is >85% of that at the center.

If the sensitivity of the equipment for any gamma emitter in the 0.5–2.0-Mev range is expressed as three times the standard deviation, the sensitivity for a 60 lb sample is ~500 $\mu\mu c$ in 1-min sample and background counts and ~50 $\mu\mu c$ in a 20-min count.

* * *

Ham samples were prepared and chemically analyzed by Messrs. T. Wall and Son of England.

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Impurities in Commercial Sodium

By **C. H. LEMKE, N. D. CLARE** and **R. E. De SANTIS**
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We have found that standard or slightly modified wet-chemical analytical methods are satisfactory for determining sodium impurities that are significant in sodium intended as a reactor coolant or as a reductant for refractory metals such as zirconium. We have also found that sodium from several commercial sources meets purity requirements.

Oxygen impurity in sodium was not included in this study since extensive work has already been reported (*1*). Little has been published, however, on the contamination levels and analytical techniques for the determination of the elements listed in the table.

Preliminary study suggested that standard analytical methods could be applied, providing the sodium sample was first converted to the chloride. It remained to be demonstrated that the methods, with or without modification, were satisfactory in the presence of large amounts of sodium chloride, or that the contaminant could be separated for determination. Phosphorus, tin and lead were separated by coprecipitation with iron. Boron, lithium, potassium and the lanthanide group required separation methods or combinations of methods new to sodium analysis.

Unless otherwise noted, 20-gm samples of sodium were dissolved in 70% methanol–30% water solution under an inert atmosphere. These solutions were made slightly acid with hydrochloric acid, concentrated until saturated with NaCl, then diluted to 250 ml with distilled water.

Analytical methods:

Aluminum. Colorimetry, 8-hydroxyquinoline method (*2*). 125-ml aliquot NaCl soln.

Boron. Colorimetry. 1 gm Na dissolved in water under nitrogen, put through Amberlite IRC-50 ion-exchange resin and received in lime slurry. Boron determined with curcumin (*3, 4*).

Cadmium. Colorimetry, dithizone method (*5*). 125-ml aliquot NaCl soln. 10-cm cell used in Beckman spectrophotometer. 50 ppm Zn added did not interfere.

Hafnium (and zirconium). Colorimetry, sodium alizarin sulfonate (*6*). 50-ml aliquot NaCl soln. Color development only 1 hr. Color read against Zr standard and reported as Hf.

Lanthanides. Colorimetry. 8-hydroxyquinoline treatment (*7*) precipitates lanthanides, Ca and Fe. Lanthanides are reprecipitated by ammoniacal ammonium citrate (*8*) and determined colorimetrically with sodium alizarin sulfonate (*9*); colors are read against lanthanum standard and multiplied by (at. wt. Lu)/(at. wt. La) = 1.26 so that inaccuracies would be high rather than low.

Lead and tin. Polarography. Tin and lead coprecipitated with ferric iron and determined together polarographically. Precipitated Pb and Sn from another sample boiled to dryness with strong hydrobromic acid and bromine to volatilize tin; Pb determined polarographically and Sn by difference.

Lithium. Colorimetry, "thoron" method (*10*). 10 gm Na dissolved in 200 gm methanol. Na removed by precipitation with HCl gas and treatment with ether-alcohol solution (*2*). Ca is precipitated by carbonate in potassium hydroxide used in thoron method.

Phosphorus. Colorimetry (*11*). 125-ml aliquot NaCl soln. Phosphorus precipitated with ferric chloride and dissolved with 10 ml 1:3 warm H_2SO_4 and treated with 2 ml hydrofluoric acid, evaporated to fuming and diluted to 25 ml. 5 ml of 10% hydroxylamine hydrochloride is added and solution boiled for 5 min. Color is developed as described in ref. *11*.

Potassium. Gravimetric method. Sodium chloride precipitated with dry HCl gas (*12*). Potassium precipitated and weighed as potassium tetraphenylboron (*13*).

Tungsten. Thiocyanate–stannous chloride method (*14*) modified by adding 12 ml of concentrated hydrochloric acid instead of 20 ml recommended and diluting until any salt precipitated just redissolves. Used 25-ml aliquot NaCl soln.

Zinc. Colorimetry, dithizone method (*2*). 25-ml aliquot NaCl soln. Zn separation from NaCl not necessary.

Data on Analytical Reliability

Element	*Reliability of methods**		*Specified impurity limits (ppm)*	*Found in commercial sodium (ppm)*
	Amount added (ppm)	*Amount determined (ppm)*		
Aluminium	10,10,10	9.6,11.0,10.7	10	1–4
Boron	1.74 gm NaOH sample: 0.20	0.23	0.25	0.10–0.17
	1.0 gm Na sample: 0.20,0.20,0.50,1.00	0.26,0.20,0.51,0.95		
Cadmium	0.20	0.21	0.25	<0.05
Hf (and Zr)	Zr added: 2.5,2.5	2.3,2.3	10	2
Lanthanides	La:5.0,5.0,10.0,15.0 15.0,25.0,Gd:5.0; Sm:5.0;Yd:5.0	La5.8,7.5,11.0,17.0, 15.3,25.0;Gd:4.6; Sm:4.6;Yd:4.7	5	3.4–5.4
Lead and tin	1.4 Pb, 0 Sn	1.5	Pb:10†	Pb ≤ 1
	0 Pb, 1.2 Sn	1.3	Sn:10†	Sn ≤ 1
Lithium	0.3,0.3,0.3,0.5, 0.5,0.5	0.3,0.2,0.2,0.5 0.4,0.4	0.5	<0.06–0.36
Phosphorus	5,10	5,9	10	<1
Potassium	20,40,50,60,80,100	19,36,46,56,80,100	200†	86–180
Tungsten	5,25	5,25	25	3–7
Zinc	Na sample: 10,50	9,53	50	2–5
	NaCl sample: 50	49		

* In cases where more than one sample was determined, amounts added and amounts determined are given in the same order.

† These specification values are for reactor-coolant application; all others are for zirconium manufacture.

In-Pile Sodium Contamination

The analysis of sodium while in use as a reactor coolant is not nearly as satisfactory as analysis for impurities in fresh sodium.

Oxygen measurement is in perhaps the best shape. Plugging meters are almost automatic and reliable. The chemical analysis on which the meters depend for absolute accuracy, however, is uncertain. This uncertainty stems as much from uncertainties about the sample as from chemical techniques, which are satisfactory for oxide concentrations of <20 ppm that are tolerable in most reactor applications.

The use of even higher liquid-metal-coolant temperatures places more importance on the carbon content of sodium. Above about 900° F, carburization and decarburization of steels in contact with sodium occurs. Approaching 1,200° F, substantial short-term fuel damage may be sustained. This is a particular hazard with thin-walled cladding and bellows. Only a few ppm can be tolerated whereas traditional analytical methods (carbon conversion to CO_2 and measurement by an absorption apparatus) have a useful lower limit of 20 ppm. Another method is to follow the damage to thin material samples suspended in the sodium stream, but this is crude and laborious, substituting metallurgical examination for process instrumentation. Hot traps, containing materials susceptible to carburization, are now used as a stop-gap measure to clean up the system.

Analysis for fission products in the sodium coolant, if performed within a few days after sample removal, must be done in a hot cell by wet-chemical means, as any radioactivity analysis is masked by Na^{24} activity. Currently, fission-product concentrations are inferred from Xe^{133} concentration; refined techniques are needed to better understand fission-product retention in the sodium stream. Apparently, sodium retains all the halides and "plates out" some metallic fission products at cooler locations.—R. W. Dickinson, Atomics International Div. of North American Aviation, Inc., Canoga Park, Calif.

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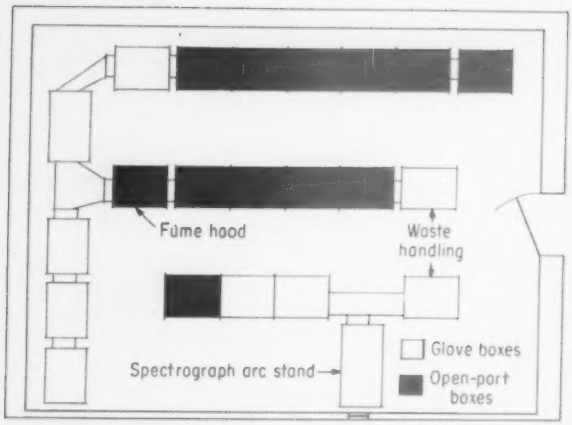


PLUTONIUM-LABORATORY LAYOUT. Samples introduced and examined in the glove-port box at lower left are prepared and weighed in the succeeding three boxes, analyzed for plutonium in the middle row, and for impurities in plutonium in the top row. Bottom row is for sample preparation for spectrograph

GLOVE AND OPEN-PORT BOXES are highly polished stainless steel with crevice-free welds to simplify decontamination. Gloved-port weighing box can be seen at far end, open-port analysis boxes along sides. Impurity-analysis row of boxes is on left; boxes for plutonium analysis are on right

Laboratory for Plutonium Chemistry

By EDMUND S. ROSZKOWSKI
New Brunswick Area Office, U. S. Atomic Energy Commission, New Brunswick, New Jersey

Although much is known about plutonium chemistry, the stability and stoichiometry of plutonium compounds have not been studied in detail, and there are no standard plutonium materials. AEC's New Brunswick Laboratory, New Brunswick, N. J.—one of only two laboratories that AEC operates directly—has installed a $125,000, 1,000-ft² facility for the preparation and study of appropriate plutonium compounds that can be used as standards.

These studies will include methods of preparation and the effects on the compounds of such processes as disproportionation, polymerization, air-oxidation and alpha-induced reactions. Since extreme care is needed to prevent the accumulation of plutonium in the human body (maximum permissible body burden is 0.0005 μg or 0.008 μc), the heart of the New Brunswick facility is a glovebox and open-port-box laboratory for handling the plutonium. Other rooms in the facility are for the emission spectrograph, counting and change of clothing by personnel.

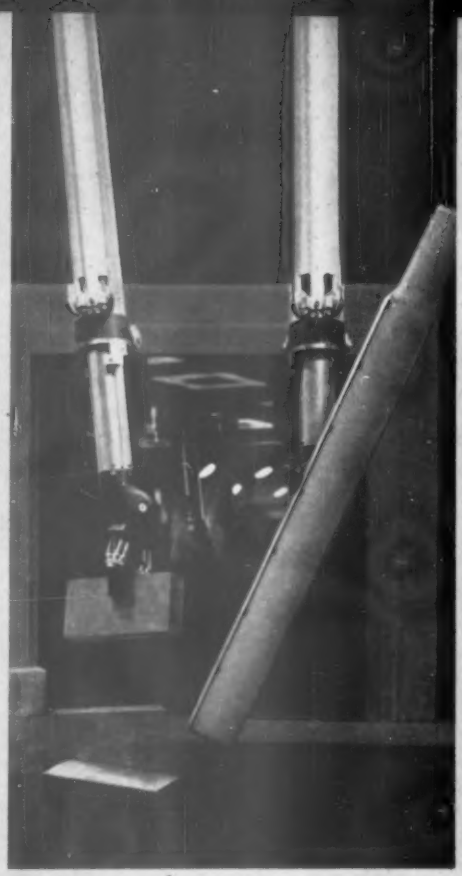
The plutonium-laboratory layout is shown in the drawing, and some of the gloveboxes and open-port boxes are shown in the photograph. The 12 open-port boxes are satisfactory for work with plutonium solutions because of the lower likelihood of contamination from solutions.

The boxes (manufactured by S. Blickman, Inc.) incorporate improvements over older designs. The sloping fronts increase headroom for the operator, and the glass fronts provide a full view of the box interiors. Twin, fireproof absolute filters in each box can be replaced singly without interrupting air flow. Pneumatically operated, guillotine-type doors connect the gloveboxes to the other boxes.

The arc stand of the spectrograph is in a glovebox next to the wall of the spectrograph room; the arc beam is then transmitted through quartz windows to the analyzer in the adjacent room. This arrangement avoids contamination of the instrument.

Laboratory ventilators change the air every 3 min. Air flow is from the building foyer and counting room into the personnel change room, then into the glovebox laboratory and out through the glovebox exhausts. Laboratory air is ¼ in. H_2O below atmospheric pressure, and gloveboxes are ½ in. H_2O below laboratory air pressure. The exhaust air, which goes through fireproof, absolute filters in the gloveboxes, is further filtered in the laboratory-building penthouse and discharged from a stack 45 ft above the ground. The air is sampled continuously with filters, and the samples are counted weekly.

Liquid wastes from the gloveboxes, lavatory and clothes washer are collected in two 500-gal underground tanks, which are used alternately. If the activity level is low enough, the filled tanks are dumped into the main plant effluent. If the activity is ever too high, the plutonium will be removed by carrier-precipitation or ion exchange. Solid wastes are packaged and encased in concrete for dumping at sea.



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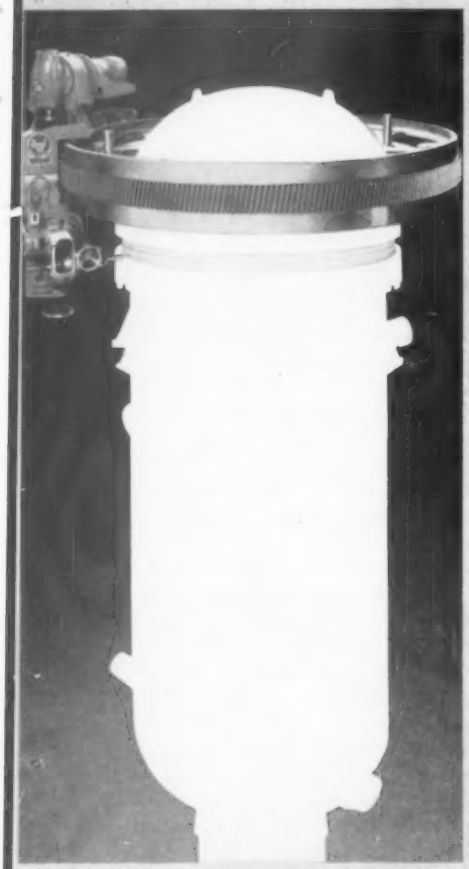

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Nitrogen, Air Acceptable to Cool ML-1

Work within the Army Reactor Program has developed design information for two gases—nitrogen and air—to the point where they can be added to the list of possible coolants for high-performance nuclear plants. High-temperature corrosion and creep tests carried out by Aerojet-General Nucleonics (see table) showed acceptable performance in nitrogen and air for both Hastelloy-X and Inconel. In tests up to 5,000 hours these two alloys satisfactorily withstood corrosion penetration, and corrosion effects upon ductility, mechanical properties and metal structure.

As a result, these two materials have been selected for fuel-element cladding in the ML-1 reactor (the gas-cooled mobile plant under joint development by the AEC and the Corps of Engineers. Hastelloy X will be the reference design alloy and Inconel the backup. The ML-1 coolant gas presently is 99.5 v/o N_2 + 0.5 v/o O_2; advanced versions of the ML-1 would use air as a coolant. As the table shows, part of the problem is that the corrosion rate for air is twice that for the 99.5 v/o N_2 + 0.5 v/o O_2 mixture. The trace amount of O_2 present in the latter acts to prevent nitriding of the clad material. Other materials included in the tests were Inconel 702, Inconel-X, Hastelloy R-235 and Inor 8. Additional alloys are now being screened for further compatibility tests.

Although the ML-1 designs considered to date are closed-loop pressurized systems, the demonstration of air as a feasible coolant opens up the possibility of open-cycle "once-through" designs for ML-1 type plants. The ML-1 would then come to resemble even more closely its cousin, the HTRE reactor series (see NU, Jan. '61, p. 45). The HTRE's (Heat Transfer Reactor Experiment), under development for the Aircraft Nuclear Propulsion Program, are also essentially air-cooled, open-cycle reactors. Operating temperatures for the two systems share the same ballpark—1,900° F measured maximum fuel temperature for HTRE-3 compared with 1,750° F for the ML-1 material tests in air. However, the longest test period reported so far for HTRE materials is the 1,000 hours accumulated by five of the original HTRE-1 nickel-chromium elements; the table shows that the Aerojet tests cover periods up to five times this or 5,000 hours.

The data given in the table for Hastelloy-X indicate a secondary creep rate for Hastelloy-X of 2.4×10^{-6} in./in. hr at 1,750° F. Thin, tightly-adherent oxide films form on both the Hastelloy-X and Inconel. Oxide film losses have not been observed except in the 5,000 hour air test.

J. S. Brunhouse, Jr. and G. W. Titus, Aerojet-General Nucleonics.

ML-1 Fuel-Clad Test Results for Nitrogen and Air

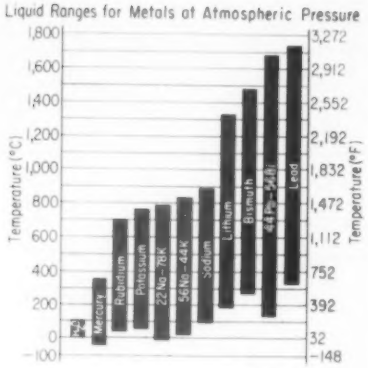
Test duration (hr)	*Test temp. (°F)*	*Atmosphere at 300 psi*	*Maximum penetration (mils)*		*After-corrosion properties for Hastelloy-X*		
			Hastelloy-X	*Inconel*	*Ultimate tensile (psi)*	*Yield strength (psi)*	*Elong. (%)*
Unexposed	—	—	—	—	117,400	66,400	41
1,000	1,750	N_2 + 0.5 O_2	0.0010	—	—	—	—
2,500	1,750	N_2 + 0.5 O_2	0.0012	0.0017	100,100	39,750	25
5,000	1,750	N_2 + 0.5 O_2	0.0015	0.0019	95,700	52,300	22
1,000	1,850	N_2 + 0.5 O_2	0.0013	—	104,800	51,000	28
2,500	1,850	N_2 + 0.5 O_2	0.0012	—	85,600	55,300	4
1,000	1,750	Air	0.0020	0.0009	—	—	—
2,500	1,750	Air	0.0027	0.0023	98,300	48,800	31
5,000	1,750	Air	0.0016	0.0020	97,500	53,000	22

2,500° F Liquid Metals Needed for Space Ion Engines

The sodium and NaK coolants of earthbound reactors operate at nearly 1,000° F. But to keep the waste-heat radiators of reactor-powered electrical ion engines for propulsion deep into outer space within a reasonable size ("less than a football field") the coolant must operate in the 2,000–2,500° F range. Today NaK-cooled SNAP (Systems for Nuclear Auxiliary Power) reactors are being built to operate with 1,200–1,300° F NaK coolant and mercury-vapor turbines, but to go to 2,000–2,500° F new reactor concepts, coolants and materials are needed. To extend liquid-metal technology beyond 1,500° F, the U. S. Atomic Energy Commission, Air Force and National Aeronautics and Space Administration are sponsoring study, research and development programs on reactor concepts, coolants, materials and components.

Among the projects:

- North American Aviation's Rocketdyne and Atomics International divisions are studying how sodium and potassium liquids and vapors up to 2,500° F corrode pump loops.
- Naval Research Laboratory and Battelle Memorial Institute are evaluating the thermodynamic and engineering properties of sodium and potassium, respectively, up to 2,500° F. Battelle also is studying high-pressure creep of Mo-0.5% Ti in sodium up to 2,000° F, as well as extending its successful irradiation studies of UC fuel clad in low-alloy niobium tubes from 1,500° F (395 full-power days in MTR) to tempera-



tures of 2,000° F and higher.

• Aerojet-General Nucleonics is studying rubidium up to 2,000° F.

• General Electric is investigating heat transfer by boiling and condensing Na and K metals.

• The Garrett Corp.'s AiResearch Phoenix division is evaluating refractory metals for turbomachinery and heat-exchange components for use with 2,000° F alkali-metal fluids.

Hotter SNAP, SPUR Reactors

While basic data are being gathered for going to hotter metals, Atomics International is applying its experience with the 3-kwe NaK-cooled SNAP-2 reactor in developing the more powerful SNAP-8 reactor. In the epithermal SNAP-8 design, 1,300° F NaK from the reactor passes through a boiler where its heat vaporizes mercury, which turns a turbine. The power-conversion equipment (boiler, turbogenerator and ~900-ft² tubular radiator) is being developed by Aerojet-General, which also will integrate the reactor and generator.

Meanwhile, the AiResearch division of Garrett Corp. is studying 300–1,000-Kwe SPUR (Space Power Unit Reactor) systems; the 300-kwe fast-neutron SPUR reactor being studied by Aerojet-General Nucleonics would generate much higher temperatures than SNAP-8. The turbine would be driven by 1,900–2,000° F rubidium, potassium or cesium vapor. Another metal would serve as reactor coolant. The heat transfer system would be built of refractory metals such as tungsten, molybdenum or niobium alloys. For SPUR, Battelle is studying fuel and materials and Westinghouse is developing the alternator.

* * *

Based mainly on a talk given by Harold B. Finger, AEC-NASA Nuclear Propulsion Manager, on November 22, 1960.

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Pressure Transients Following Loss of Coolant

By R. CASINI and F. DALLA VOLTA,* *Società Elettronucleare Italiana (SELNI), Milan, Italy*

For water-moderated and -cooled reactors, the plant containment structure must be able to withstand the pressure and temperature generated by the release of all the coolant to the interior of the container. With a sudden release, the container's internal pressure would jump to an initial peak value, then gradually decrease with condensation of vapor on the cold walls and equipment. Following this decrease, the pressure can rise again to *a second peak* depending upon the balance between the rates at which heat is generated by the reactor fission products and heat is absorbed by "sinks" such as large masses of concrete and metal within the container or dispersion to the outside atmosphere (see box). Under certain circumstances, this second peak might conceivably exceed the first.

Ordinarily designers base the plant container design on calculations of the initial pressure peak. (At present, these calculations are typically quite conservative—ways to make more realistic calculations of this problem are much needed.) Given the conditions within the container at the time of the first peak, we present here a procedure for calculating the transient pressure versus time *after* this event. Using this method the designer can check to see whether a second pressure peak will develop after coolant loss and, if so, whether it will be larger than the first. If this promises to be the situation then he can use this same method to determine the effect of added measures, such as water spray equipment, on reducing the second peak to an acceptable level.

* PRESENT ADDRESS: Westinghouse Atomic Power Department, Pittsburgh, Pa.

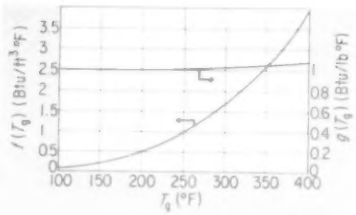


FIG. 1. Functions $f(T_g)$ and $g(T_g)$ vs. temperature of air-vapor mixture T_g. See Eq. 2 for definitions

The curve of pressure vs. time is also useful in predicting environmental hazards should there be any release of radioactivity to the interior of the container.

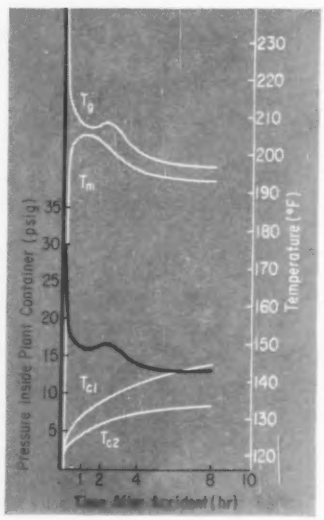
Approximations have been introduced that make our procedure feasible for hand calculation; the procedure should prove preferable to graphical and machine methods in many instances.

Assumptions

Our procedure makes the following assumptions:

- The air-vapor-liquid mixture within the vapor container after the accident is saturated.
- The temperature of the air-vapor-liquid mixture is uniform throughout the interior of the container.
- The source heat is directly released to the air-vapor-liquid mixture within the container.
- The container shell is thin enough so that it is at uniform temperature across its thickness.
- The internal concrete walls and steel plates are infinite slabs of finite thicknesses, either heated on both sides by the air-vapor mixture or perfectly insulated on one side and heated on the other side.
- No heat is transferred through the surfaces where concrete is in contact

Application of Transient Calculation to Yankee



To demonstrate the method described in this article, the authors calculated the pressure vs. time curve after a hypothetical loss of coolant in the vapor container of the Yankee Atomic Electric Co. plant. Feeding the existing plant data into the procedure described in the accompanying article the authors arrived at the solid black curve in the figure at left. Their hand-calculated curve checks reasonably well with the more elaborate machine calculations performed by the Yankee designers. The conclusion is that for the Yankee plant the second pressure peak (due to after-heat) is small compared with the initial peak and hence a plant container designed to handle the initial peak will be adequate for the subsequent pressure transients. In a different plant design the second peak might very well exceed the first. White curves show transient temperatures.

with the steel shell.

- The temperatures of the interior concrete walls and steel plates prior to the accident are uniform.
- Afterheat is the sole source of heat generated within the container after the accident. (Chemical reactions may also generate heat but these sources will be small compared with afterheat for most water reactors.)

Mathematical Description

A balance between heat sources and sinks gives the following set of differential equations:

$$Q = U_1 S_1 (T_g - T_m) + \sum_i W_{c_i} \frac{dT_{c_i}}{dt} + W_v \frac{dT_g}{dt} \quad (1)$$

$$U_1 S_1 (T_g - T_m) = U_2 S_2 T_m + W_m \frac{dT_m}{dt}$$

All quantities are defined in the box. The heat capacity of the air-vapor-liquid mixture W_v, is defined as the derivative of internal energy of the mixture with respect to temperature.

$$W_v = Vf(T_g) + Mg(T_g) + W_a \quad (2)$$

where

Definitions of Symbols

a_i	a root of a tan a = L_i	T_g*	temperature of air-vapor mixture °F
c_i	conductivity of i-th slab material Btu/ft hr °F	$\overline{T}_g$†	average temperature of air-vapor mixture during n-th interval °F
E_v	internal energy of saturated vapor Btu/lb	T_{go}†	temperature of air-vapor mixture at start of n-th interval °F
E_m	internal energy of liquid Btu/lb	T_m*	temperature of container shell °F
H_i	u_i/c_i ft^{-1}	U_1	heat transfer coefficient between air-vapor mixture and container shell Btu/ft²hr°F
I	defined in Eqs. 10 and 11	U_2	heat transfer coefficient between container shell and atmosqhere Btu/ft²hr°F
k_{cv_i}	$\frac{W_{c_i}}{W_v} \cdot k_{1m}$ hr^{-1}	V	net container volume ft^3
k_{1m}	$\frac{U_1 S_1}{W_m}$ hr^{-1}	v_a	specific volume of saturated vapor ft^3/lb
k_{mv}	$\frac{W_m}{W_v} k_{1m}$ hr^{-1}	W_a	heat capacity of air within container Btu/°F
k_{qv}	$\frac{q}{W_v} k_{1m}$ $°F/hr^{1.2}$	W_{c_i}	heat capacity of i-th internal concrete or steel slab Btu/°F
k_{2v}	$\frac{U_2 S_2}{W_v} k_{1m}$ hr^{-2}	W_m	heat capacity of shell region exposed to air-vapor moisture Btu/°F
k_{12}	$\left(1 + \frac{U_2 S_2}{U_1 S_1}\right) k_{1m}$ hr^{-1}	W_v	heat capacity of air-vaqor-liquid mixture Btu/°F
l_i	half thickness of ith slab, if uninsulated; or total thickness if insulated ft	τ	time since accident hr
L_i	$l_i H_i$	τ_p	time reactor was at power hr
M	total water mass (in form of liquid and vapor) released into container lb	μ_i	heat transfer coefficient between air-vapor mixture and i-th slab wall Btu/ft²hr°F
Q	fission-product after heat Btu/hr	α_i	thermal diffusivity of i-th slab ft^2/hr
r_1, r_2	roots of Eq. 9		
S_1	internal surface area of container available to absorb heat ft^2		
S_2	external surface area of container available to transfer heat to atmosphere ft^2		
T_{c_i}†	average temperature of i-th internal concrete or steel slab at τ_n °F		
$\overline{T}_{c_{oi}}$†	average temperature i-th slab at start of n-th time interval °F		

* These temperatures are relative to atmospheric temperature; T_x = (observed temperature in region x) − (atmospheric temperature).

† These temperatures are relative to the slab temperature prior to incident.

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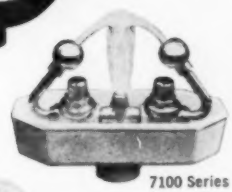
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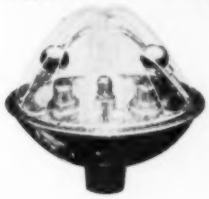

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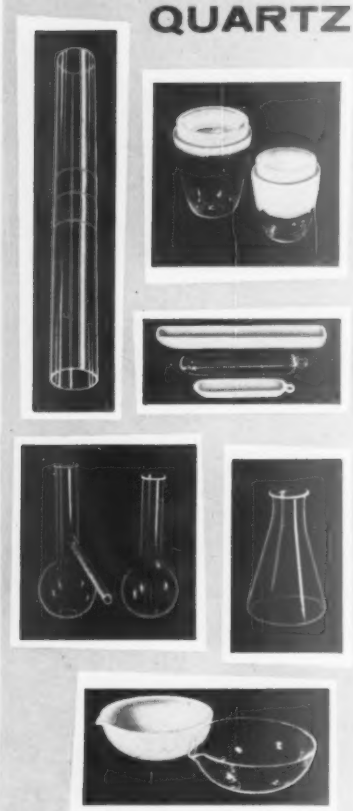

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Pressure Transients

This article starts on page 84

$$f(T_g) = \frac{d}{dT_g}\frac{E_s - E_w}{v_s}$$

$$g(T_g) = \frac{dE_w}{dT_g}$$

Plots of functions f and g appear in Fig. 1.

We can combine Eqs. 1 by eliminating T_g

$$\frac{d^2T_m}{dt^2} + (k_{m_0} + k_{12})\frac{dT_m}{dt} + k_{2_0}T_m = k_{q_0}\varphi(\tau,\tau_p) - \sum_i k_{e_{i_0}}\frac{dT_{e_i}}{dt} \quad (3)$$

where the k's (see box) are combinations of the constants introduced above. In Eq. 3, the decay heat source has been expressed as

$$Q = q\varphi(\tau,\tau_p) \quad (4)$$

where q is a proportionality constant, τ is the time since shutdown and τ_p is the time at power. Equation 3 is nonlinear, because the heat capacity of the air-vapor-liquid mixture and heat-transfer coefficients strongly depend upon temperature; also the relationship between the temperatures of the mixture and internal slabs is complex, involving an integral of a function of time and temperature even in the simplest geometry. Since an exact solution appears very difficult, we use a step-by-step iteration in time. Each time step assumes a constant temperature of the air-vapor-liquid mixture, hence an average value of W_v (and of U_1, U_2, provided a tentative average temperature T_m is assumed).

The solution of Eq. 3 for each time interval (using the method of variation of parameters) then becomes

$$T_m = \frac{1}{r_1 - r_2}\left[Ae^{r_1t} + Be^{r_2t} + I_{1_q} - I_{2_q} - \sum_i (I_{1_{e_i}} - I_{2_{e_i}})\right] \quad (5)$$

and

$$T_g = \frac{1}{k_{1m}(r_1 - r_2)}\left[\left(Ae^{r_1t} + I_{1_q} - \sum_i I_{1_{e_i}}\right)(r_1 + k_{12}) + \left(Be^{r_2t} - I_{2_q} + \sum_i I_{2_{e_i}}\right)(r_2 + k_{12})\right] \quad (6)$$

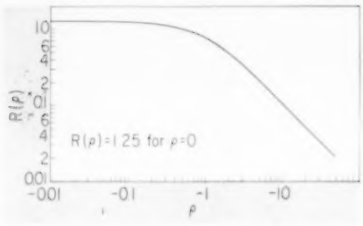


FIG. 2. Function R vs. ρ. See Eq. 13

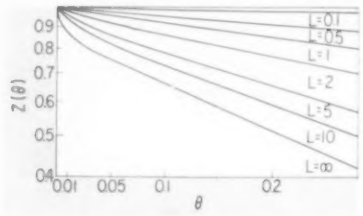


FIG. 3. Function $Z(\theta)$ vs. θ for various values of L. See Eq. 15

In these expressions

$$A = T_{m_0}(r_1 - r_2) - B \quad (7)$$

$$B = (r_1 + k_{12})T_{m_0} - T_{g_0}k_{1m} \quad (8)$$

are calculated by introducing the boundary conditions for T_m and T_g in every interval ($T_m = T_{m_0}$, $T_g = T_{g_0}$ at the beginning of each interval). r_1, r_2 are the roots of the auxiliary equation

$$r^2 + (k_{m_0} + k_{12})r + k_{2_0} = 0 \quad (9)$$

and

$$I_{1,2_q} = k_{q_0}e^{r_{1,2}t}\int_0^t \varphi(\tau,\tau_p)e^{-r_{1,2}t'}\,dt' \quad (10)$$

$$I_{1,2_{e_i}} = k_{e_{i_0}}e^{r_{1,2}t}\int_0^t \frac{dT_{e_i}}{dt'}e^{-r_{1,2}t'}\,dt' \quad (11)$$

where t is the length of an interval. [Equations 10 and 11 define the *four* functions $I_{1_q}(r_1)$, $I_{2_q}(r_2)$, $I_{1_{e_i}}(r_1)$ and $I_{2_{e_i}}(r_2)$.]

Integral Solutions

To proceed farther we need more workable expressions for $I_{1,2_q}$ and $I_{1,2_{e_i}}$. If a Way-Wigner expression is used for the decay heat source

$$Q = q[\tau^{-0.2} - (\tau + \tau_p)^{-0.2}].$$

If τ is negligible compared with τ_p, Eq. 16 becomes

$$I_{1,2_q} = k_{q_0}\left[\tau^{0.8}R(r_{1,2}\tau) - \tau_0^{0.8}R(r_{1,2}\tau_0)e^{r_{1,2}t} + \frac{\tau_p^{-0.2}}{r_{1,2}}(1 - e^{r_{1,2}t})\right] \quad (12)$$

where: τ_0 = time elapsed between reactor shutdown and the beginning of the interval.

Here

$$R(\rho) = e^{\rho}\left[1.25 + \sum_{n=1}^{\infty} \frac{\rho^n}{n!(n+0.8)}\right] \quad (13)$$

and $\rho = r_{1,2}\tau$. Function $R(\rho)$ is plotted in Fig. 2.

T_{c_i}, the temperature excess above the temperature prior to the accident, averaged on the entire ith slab volume is (*1*):

$$T_{c_i}(\tau) = T_{g1}[Z_i(\tau - \tau_1) - Z_i(\tau)] + T_{g2}[Z_i(\tau - \tau_2) - Z_i(\tau - \tau_1)] + \cdots + T_{gn}[1 - Z_i(\tau - \tau_{n-1})] \quad (14)$$

where: $T_{g1}, T_{g2} \ldots, T_{gn}$ = average mixture temperature excesses above slab temperatures prior to the accident in 1st, 2nd . . . , nth interval, respectively: $\tau_1, \tau_2 \ldots, \tau_{n-1}$ = times elapsed between the accident and the end of 1st, 2nd . . . , $(n-1)$th interval, respectively; and

$$Z_i = 2L_i^2 \sum_{j}^{+\infty} \frac{e^{-a_j^2\theta}}{a_j^2(a_j^2 + L_i + L_i^2)} \quad (15)$$

$$L_i = l_i H_i \quad (16)$$

$$\theta = \frac{\kappa_i \tau}{l_i^2} \quad (17)$$

Function Z is plotted against θ in Fig. 3 for different values of L (*2*).* This function is practically an exponential except for abscissa values fairly near the origin.

To simplify calculation of the integral in Eq. 11, we fit functions Z_i in interval $\tau_n - \tau_{n-1} \ldots \tau_n$ with exponentials $Z_i = Z_{0_i}e^{-z_i t}$. If we assume for the nth interval $\tau_n - \tau_{(n-1)} \geq \tau_{n-1} - \tau_{n-2}$ the following recurrent formulae apply ($\tau_n - \tau_{n-1} = t$):

$$T_{c_i} = \bar{T}_g + [T_{co_i} + (Z_{o_i} - 1)T_{go} - Z_{o_i}\bar{T}_g]e^{-z_i t} \quad (18)$$

$$I_{1,2_i} = \frac{k_{cv_i} z_i}{z_i + r_{1,2}} [T_{co_i} + (Z_{o_i} - 1)T_{go} - Z_{o_i}\bar{T}_g](e^{-z_i t} - e^{r_{1,2}t}) \quad (19)$$

For small values of $r_{1,2}t$, $e^{r_{1,2}t} \cong 1$, Eq. 25 can be conveniently replaced by the approximation $I_{1,2_i} \cong k_{cv}(T_{c_i} - T_{co_i})$.

* The infinite series of Eq. 15 converges very slowly for small values of the argument. Actually no data are available in the literature in the range 0–0.01; Z is not, therefore, well known in this range.

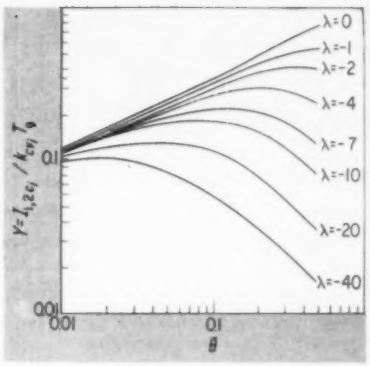


FIG. 4. Ratio Y vs. θ for various λ and $L = \infty$. See Eq. 20

Calculation Recipe

Using Fig. 1, Eqs. 2 and 9 and the definition of the k's, plot r_1, r_2 and k_{qv} against temperature in a suitable range (k_{cv_i} is proportional to k_{qv}).

Choose an interval of time sufficiently small so that the temperature of the air-vapor-liquid mixture changes only slightly and a tentative average temperature can be assigned to the mixture.

Calculate expressions A, B, I_{1q}, I_{2q} from the plots of r_1, r_2 and k_{qv} and Eqs. 7, 8 and 12 and the plot of R *vs.* ρ in Fig. 2.

Make a semilogarithmic plot of function Z vs. time and fit a straight line in the interval t; from this line and Eq. 19 calculate Z_o, z, I_{1c}, I_{2c}.

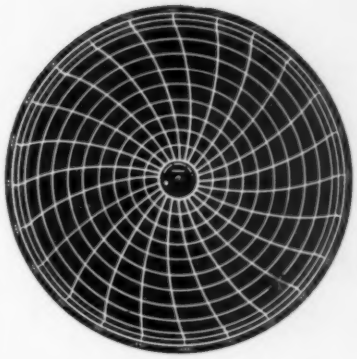
Determine T_m and T_g through Eqs. 5 and 6 and calculate the pressure of the air-vapor mixture as the sum of partial pressures of saturated vapor and air. If the average temperature in the interval is significantly different than the average temperature that was assumed, repeat the calculation.

Apply a similar procedure to subsequent time intervals, using obtained values of T_g, T_m and T_{c_i} as initial values T_{go}, T_{mo} and T_{co}. To use Eqs. 18 and 19, fit a semilog plot of function Z vs. time by a straight line in interval $\tau_n - \tau_{n-1} \ldots \tau_n$ (assume $\tau_n - \tau_{n-1} \geq \tau_{n-1} - \tau_{n-2}$).

Slowly Varying T_g

If T_g, varies only slowly over the total-time interval under consideration, constant values T_g and W_v may be assumed. The following expression then replaces Eq. 19

$$I_{1,2_i} = 2k_{cv_i}\bar{T}_g L_i^2 \sum_{j=1}^{+\infty} \frac{e^{\lambda_{1,2_i}\theta} - e^{-a_j^2\theta}}{(a_j^2 + \lambda_{1,2_i})(a_j^2 + L_i + L_i^2)} \quad (20)$$



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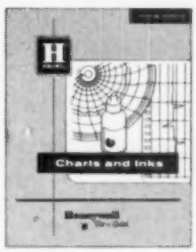

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Pressure Transients

This article starts on page 84

where:

$$\lambda_{1,2_i} = \frac{r_{1,2} \cdot l_i^2}{\kappa_i} \qquad (21)$$

and θ and L_i are defined as in Eqs 16 and 17.

The function $Y = I_{1,2c_i}/k_{cv_i}\bar{T}_g$ is plotted vs. θ in Fig. 4 for different values of λ and for $L = \infty$, the most common case. If $\lambda = 0$, Y is identical with $1 - Z$; $\lambda = -\infty$, Y is identically 0. For small values of $|\lambda|(|\lambda| < 0.2)$, Y may be approximated by $e^{\lambda\theta}(1 - Z)$. The series of Eq. 20 converges rapidly for large values of θ.

Under our assumption of constant values of T_g and W_v, the terms $I_{1,2c_i}$ in Eq. 6 are now calculated from Eq. 20 and Fig. 4. More generally, this same simplified procedure may be applied in a preliminary evaluation by calculating W_v at temperature T_{go} and assuming an average value of T_g in Eq. 20.

Pressure Suppression

In Eq. 3 no water spraying into the vapor container is considered. If finely atomized cold water is sprayed as a corrective measure to prevent excessive pressure and temperature peaks, the term $k_{1m}k_{fv}T_w$ must be added to the right hand of Eq. 3 (T_w is the water temperature before spraying, $k_{fv} = F/W_v$, and F is the product of specific heat and flow rate of sprayed water). The coefficients of dT_m/dt, and T_m in Eq. 3 become $k_{ms} + k_{12} + k_{fv}$ and $k_{2v} + k_{12} \cdot k_{fv}$, respectively. Instead of Eq. 9, equation

$$r^2 + (k_{ms} + k_{12} + k_{fv})r + k_{2v} + k_{12}k_{fv} = 0 \qquad (22)$$

should be used and expression $I_{1f} - I_{2f}$ should be added between brackets in Eq. 5

$$I_{1,2f} = \frac{k_{1m}k_{fv}T_w}{r_{1,2}}(1 - e^{r_{1,2}t}) \qquad (23)$$

Eq. 6 must be modified accordingly. With these substitutions the calculations then proceed according to the recipe given above.

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2. H. Grover, *Zeitschr. d. Ver. Deutsch. Ing.* **69**, 705 (1925)

Bolt Tensioner Speeds Vessel Closure

By ROBERT G. MICHEL and STEPHEN P. WNUK, JR.
Allis-Chalmers Manufacturing Co., Milwaukee, Wisconsin

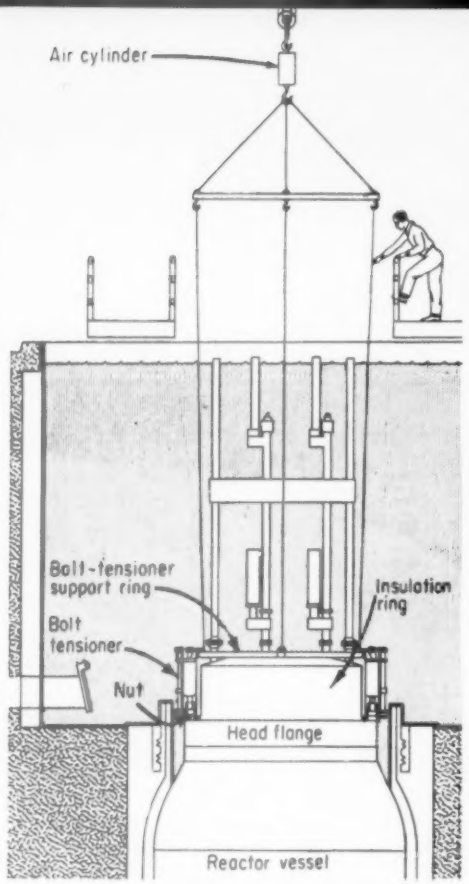
Hydraulically-actuated bolt tensioners speed fastening the flanged closure of the pressure vessel for the Northern States Power Co. reactor. No less than 48 bolts are involved in sealing the vessel's 91-in.-dia opening. Figures 1 and 2 show how a simplified hydraulic bolt tensioner operates; by using a double-stage tensioner instead of the single-stage unit we can reduce the tensioner diameter while nearly doubling its pulling capacity (336,000 lb max.). Figure 3 shows the parts for an improved two-stage tensioner.

Bolting and unbolting the 3-in. studs by ordinary methods would be cumbersome and would add to reactor downtime, particularly since we must protect maintenance personnel by working through 18 feet of shield water. Torque wrenches could be used to tighten the studs to the desired accuracy, but galling and wear problems associated with this method make it very undesirable. To turn the nut freely and prevent galling, we could elongate the bolt by heating it before we move the nut, but this would require draining the shield water. Even without the water problem it would take at least six hours to fasten the closure within ±10% accuracy. Hydraulic bolt tensioners are very attractive because they do not have these problems and they operate considerably faster.

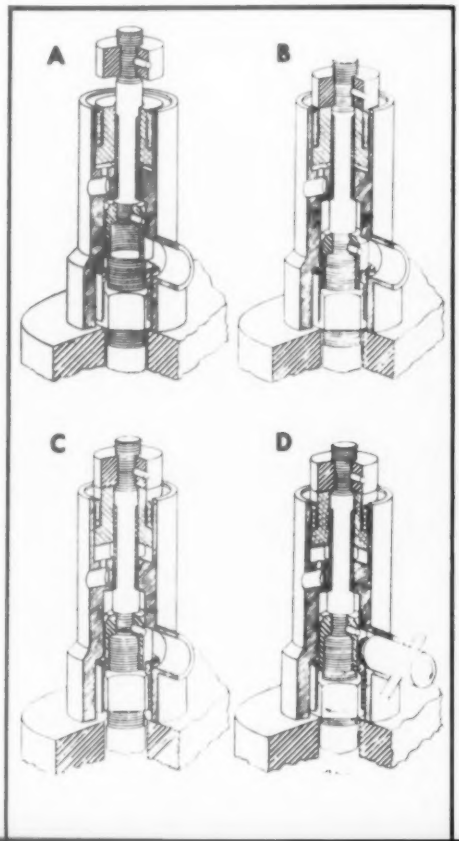
We are testing the bolt tensioner on a full-scale vessel closure under 18 feet of water to refine our operating technique. Similar bolt tensioners will be used on the Elk River reactor vessel closure.

* * *

John L. Biach and F. H. Stillman of Biach Industries, Cranford, N. J., have assisted us in adapting their tensioners for this application.

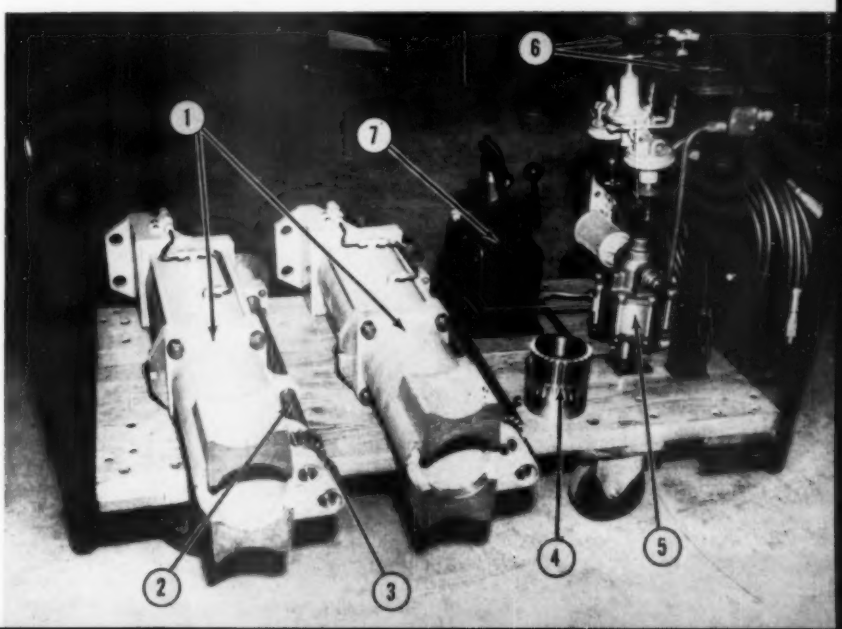


1. WHEN CLOSING the vessel, we use a long tool to put each nut on the stud and thread it down to flange by hand. Then, with a small crane, we lower the rig supporting the tensioners down through water toward a stud on the vessel flange; insulating ring on vessel cover and chamfer on tensioner housing act as guides



2. SINGLE-STAGE TENSIONER (at left) has spring-loaded feeler (not shown) that supports puller bar above stud threads until (A) nut socket and housing rest on flange; then we use long tool to thread puller bar onto stud hand-tight (B); after which we stress and stretch stud (C) by applying hydrostatic pressure until gear teeth engage those on nut socket (D); then we thread nut to flange, unfasten puller bar and remove tensioner

3. TWO-STAGE BOLT-TENSIONER components (shown disassembled below) for reactor for Northern States Power Co. We minimize the required flange area by having gear teeth on the nut (4), eliminating socket; thus geared shaft (2) on right side of tensioner (1) drives nut directly through idler gear (3). Air-operated (100 psi) hydraulic pump (5) (driving 2, 3 or 4 tensioners) pressurizes the 8,000-psi water-hydraulic drive system, which we control by manual valves (7); bourdon pressure gages (6) tell bolt load and stress; we can tension studs within ±5%



Statistical Design of In-Pile Screening Tests

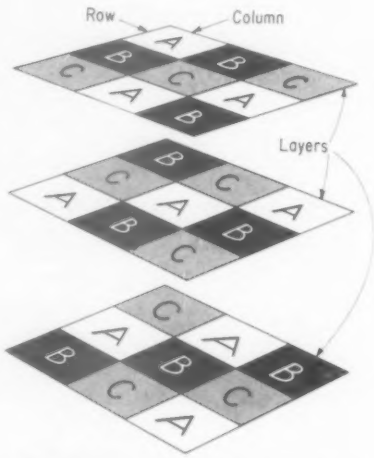
By F. H. TINGEY, *Phillips Petroleum Co., Atomic Energy Div., Idaho Falls, Idaho*

Even the simplest of in-pile experiments—capsule programs to screen materials—cost enough in time and money to warrant statistical methods of experimental design to ensure the greatest amount of information from the invested effort. Typically, proper experimental design can halve the number of experimental runs needed. (For an example of a practical application in which such a saving occurred see box on p. 91.) Proper experimental design also requires that the whole program (including the statistical analysis of the results) be planned prior to collecting a single item of data. Consequently the experimenter is forced to "do his thinking" before he expends time, effort and expense on the experiments themselves. This aspect of statistical design alone often justifies its use.

Statistical experimental design has formed the subject matter for several excellent tests (*1–3*). Entire catalogs of designs (*4, 5*) are now available to the experimenter to assist him in his research effort. One familiar entry in such catalogs is the so-called factorial design—a design that provides for one experiment for each possible combination of experimental variables. More highly specialized designs require far fewer observations than the factorial. These "reduced" specialized designs are appealing to industry in general and are particularly suited to the expensive field of in-pile testing. Reduced designs, however, result in a certain loss of information. Precisely for this reason statistical design grows in importance because it seeks to minimize this loss. This is true regardless of how few or how many total experiments are to be performed. Intuition cannot approach formal statistical experimental design in effectiveness.

Application to In-Pile Tests

In the simplest form of in-pile test, small samples of, say, fuel alloy are screened with regard to certain performance criteria. These may range from simple go-no-go criteria (perhaps, cladding blisters vs. no cladding blisters), to highly elaborate and precise measurements (for example, cladding temperature and internal pressure).



LATIN CUBE array of specimen types A, B, and C cancels effects of flux gradients across sample holder during irradiation experiment in test reactor

Suppose we want to subject specimens of several different types of fuel alloy to various flux levels for extended exposure periods. The data generated consist of physical and nuclear measurements before and after irradiation for each specimen. We will want to compare the changes as well as terminal properties of the specimens.

The reactor imposes certain physical limitations: only a limited number of experimental positions can be made available; neutron flux cannot be measured precisely within each position; thermal cycling of specimens takes place and depends in part upon the position of the specimen within the reactor.

If possible, one would like to arrange the test specimens within the reactor so that all factors except specimen type are constant. This might be accomplished with a sample holder that holds several specimens of each type.

Experimental error (see box, p. 91) will show up as random variation in the results. Replication—exposing more than one specimen of each type to each particular set of conditions—provides information as to the magnitude of the error which can then be used to determine the significance of the observed differences between specimens. Also, under certain assumptions, experimental design provides the means to estimate experimental error without replication.

Because of vertical and horizontal flux gradients within the test region the specimens must be arranged in the sample holder in a very particular manner to prevent this factor from invalidating the comparison. A Latin Cube array, a particular three-dimensional arrangement that satisfies this requirement, is given in the figure for three specimen types (A, B, C) within the holder.

The average of the nine results for one specimen type is an average over 3 results in each row, 3 in each column, and 3 in each layer, and similarly for the average of the 9 results in one row, column, or layer. Therefore any inherent differences between rows, columns or layers because of flux gradients are removed from the comparison of the averages for specimen types with each other or with the over-all average.

The statistical analysis of this array (*6*) involves the resolution of the total variation in the 27 results for a particular characteristic into component parts identified with differences between layers, between rows, between columns and between specimen types. Under the assumption that combined effects are negligible, an experimental error estimate can be obtained and this in turn used to test the significance of the between-specimen component.

The procedure and statistical analysis can be extended to experiments conducted in several test regions. The basic design outlined above is repeated in each region. As a result an additional component is introduced in the analysis, i.e., differences between

test regions. However, the comparisons between specimens still remain valid providing the effects of the various factors act independently of one another.

Incomplete-Block Design

The above design required 27 specimens arranged in a three-dimensional array even though only three different specimen types were involved. Space and heat-removal limitations often preclude such a design; all specimens cannot be tested in the same test region. However, at the price of some complication, we can use designs in which every specimen is not equally represented in each test region. These are called "incomplete" block designs (a "block" is the experimental array of specimens). If comparisons between specimens are to be made with equal precision such designs should have *balance*, i.e., any two specimens should occur together in the same block the same number of times as any other two. An application of this design to the screening of, say, four alloy types (A, B, C, D) in sets of three utilizing four test regions is given in Table 1.

Even though all specimens do not occur in the same test region, unbiased comparisons between specimen types are still possible (*7*).

The experimental error is estimated from the replication that takes place over all test regions. The total variation in the complete set of observations resolves into that identified with region-to-region changes, that associated with differences in specimen types and experimental error. Designs of this type exist for a great variety of treatments (specimens),

TABLE 1—Incomplete Block

Test region			
1	*2*	*3*	*4*
A	A	A	B
B	B	C	C
C	D	D	D

TABLE 2—Symmetrical Incomplete Block

	Test regions			
Rows	*1*	*2*	*3*	*4*
1	B	D	C	
2	C	A		D
3	A		D	B
4		B	A	C

blocks (test regions) and treatments per block (*8*). Since the space occupied by the samples in each test region is considerably less than that in the Latin Cube design, the flux gradient over the samples is very likely not as severe. This design makes no attempt to cancel out the effect of this variation. Instead we depend on the randomization of unfixed variables that is customarily carried out in blocking designs to prevent bias. Thus any features of the arrangement not detected by the design such as the numbering or designation of test regions, the allocation of the specimens to the regions, or the position of the specimens within the sample holder are randomized.

Symmetrically Balanced Block

Some balanced incomplete block designs have a property of symmetry

Definitions and Essentials

An in-pile screening experiment can usually be characterized by:

- Fixed parameters of the experimental complex (these are maintained as nearly constant as possible from experiment to experiment).
- Experimental factors consisting of:

(a) conditions under the control of the experimenter, usually constant for a given experiment, but intentionally changed from level to level between experiments

(b) conditions imposed by the experimental tool or environment and over which the experimenter may have little control; such factors may unintentionally change between or even within experiments.

- One or more observable (and usually measurable) responses of the system resulting from the sum-total effects of parameters and variables.

The problem is to determine what particular combinations of levels for the intentional factors should define the total investigation. The design should minimize the influence of unintentional variables on the comparisons and test to be made. It should provide a "yardstick" with which to differentiate true effects from experimental errors.

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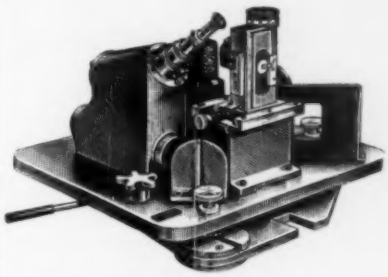

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that enables one to introduce an additional factor into the design or remove an additional source of variation from the comparisons to be made. For example, taking the design of Table 1 for four alloy types blocked in sets of three over four test regions, we introduce in Table 2 an additional row which gives one empty position in each test region. This design is balanced with respect to both rows and columns (test regions). Thus, if the relative flux gradient within a test region is approximately the same from region to region, this arrangement of the specimens within the regions removes this flux variation from the alloy comparison. The experiment is more discriminating than could be expected if the specimens were randomly assigned positions within each test region. This design, sometimes called a Youden's square, corresponds to a two-dimensional layer of "squares" of the Latin Cube in the first example if the missing letters are supplied in the rows. The statistical analysis (*9*) is very similar to that for the first example when an adjustment for missing values is made.

RMF Comparison

Another blocking-type example is provided by reactivity measurements against a "standard." The Reactivity Measurement Facility, a zero-power reactor located in the MTR Canal, is used to determine fuel and poison content of small samples in this way. A two-place sample holder allows alternate measurements on two different specimens as the holder is oscillated vertically in the center plane of the reactor.

The experimental procedure familiar to most experimenters is to load, for a given group, the "standard" with each test sample in turn and in this manner generate data for the comparisons. To make the comparisons, a number of runs are made with the sample in each of the two positions. The design for this investigation consists of three replications of the basic design in Table 3. A run is defined as a measurement on sample and standard each in a given position in the holder. A set consists of the two runs obtained by interchanging the positions of the sample and standard in the holder. For three replications and four samples (A, B, C, D) plus a standard (S) a total of 12 sets of 2 runs each would be required.

Under this design the standard and a given specimen are compared by differencing the measurements obtained in each pertinent run and averaging over the 6 runs involving the given sample. Since the effects of sample-holder position are eliminated the precision associated with a comparison can be expressed in terms of the experimental error of the measurements. This in turn is related to a statistic called the variance (*10*).

If V is the variance of any given measurement for the design of Table 3, the average difference between standard and sample over the three replicates has variance $V/3$. The

GCRE Screening Program

An experimental design of the Youden Square type was developed for an experiment on fuel samples for the gas cooled reactor experiment conducted in the Materials Testing Reactor. This experiment sought to determine the effects of variation in fuel geometry, exposure and clad clearance on fission-gas release, stability and other fuel-element characteristics. Because of test-space limitations and the complex nature of each single experiment the total number of experiments was severely limited.

The basic design is given in the table. The entire set was twice replicated to provide more sensitive comparisons and a means for determining the experimental error. Although the blocking is in three sets of two with regard to rows (geometry) and columns (burnup) it is of the same family of designs as Table 2. The design assumes that the factors act independently of one another and that all other variables intentional or unintentional are essentially constant over the course of the total experiment. The statistical analysis provides unbiased estimates of burnup, geometry and temperature effects as well as a means for testing the significance of each.

GCRE Experimental Design

Experimental factors	*Constant factors*	
Total burnup	Enrichment level	Clad clearance
Slug geometry	Heat-transfer medium	Clad material
Clad temperature	UO_2 density	

Experimental Values

	Clad temperature (°F) at burnups (Mwd/tonne)		
Slug geometry	*3,000*	*6,000*	*13,000*
Solid	1,300° F	1,600° F	
Cored	1,600° F		1,300° F
Cored with bushing		1,300° F	1,600° F

This example is typical of the savings in total effort that can be anticipated through statistically designed programs. Suppose in this study the classical "one-variable-at-a-time" approach had been used. Assuming, as for the statistically designed program, that the combined effects of the factors are negligible, we could in turn investigate the effects of a single factor by holding the other two factors constant at given levels and then conduct experiments over the levels of the third. For the factors and levels of factors for this example this procedure also results in six basic experiments (or 12 altogether with replication). However, for the twelve statistically designed experiments the comparisons between the geometry types essentially involve averages of four individual experiments, between burnup levels also averages of four, and between clad temperature averages of six. To have equivalent precision with the "one-variable-at-a-time" approach would require four replications of those experiments directed toward burnup (of which there are three), four of those directed toward geometry (of which there are three) and six replications each of the two experiments directed toward estimating temperature effect. This would result in thirty-six individual experiments! Through a judicious choice of experiments this could be reduced to twenty-eight. Even so, the statistical program with its twelve experiments represents a better than two-fold reduction in effort.

variance of the difference between samples appearing in different sets, for example A-B, is $2V/3$ since to compare A with B we must compare A with S on its three sets to B with S on another three sets.

Let us compare this procedure and the resulting variances to that obtained by the incomplete block design of Table 4. This design would require each specimen (including the standard) to be run with every other specimen. The technique of interchanging positions within sets would still be required. The order of sets and runs within sets would be randomized.

Under this design (*11*) the variance of any comparison between two samples (standard included) is $2V/5$. But since this design requires only 40 total observations and the Table 3 design requires 48, on an equal sample-size basis, we must multiply $2V/5$ by 40/48 which gives exactly $V/3$ for this design also. Hence both designs give the same variance for a comparison of a given specimen with its standard. However, for the comparison between any two specimens the variance under the design of Table 4 is *half* that of Table 3! This represents a considerable increase in sensitivity at no additional effort. Furthermore the design of Table 4 facilitates the removal from the comparisons of any variation that might exist between runs.

Fractional Factorial Design

The Latin Cube design and the GCRE design are both special cases of a very broad class of screening-type experimental designs called fractional factorial designs (*12*). The name is derived from the fact that these designs actually consist of a fractional selection of experiments from the group defined by all combinations of factor levels, the full factorial set. When applicable, they represent a considerably economy of effort.

In general, the reduced set for a particular case is determined from the assumptions that can be made about the significance of the combined-factor effects. The experimenter's knowledge and experience with regard to the phenomenon under investigation plays a fundamental role in formulating appropriate designs of this type.

Although we will give an in-pile test involving five factors each at two levels, the procedure is considerably

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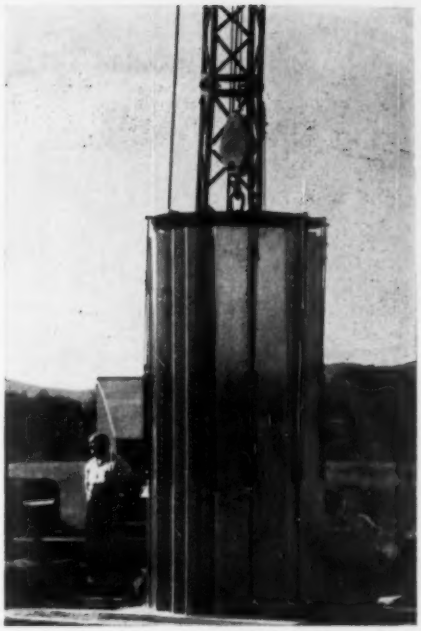

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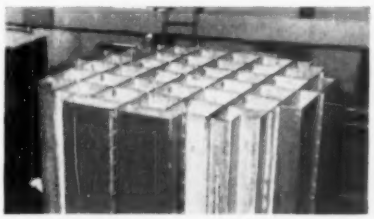

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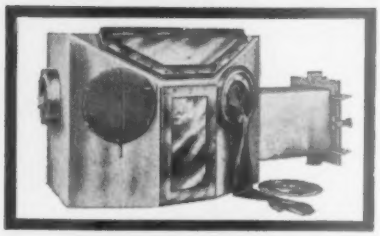

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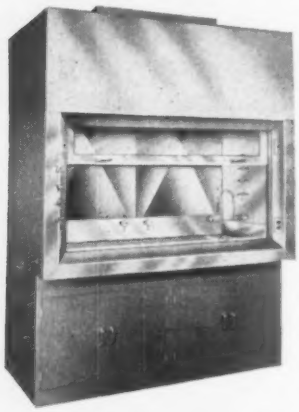

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TABLE 3—Comparison with Standard

	Sets	*1*		*2*		*3*		*4*	
	Runs	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*
Position in holder	Up	S	A	S	B	S	C	S	D
	Down	A	S	B	S	C	S	D	S

TABLE 4—Incomplete Block for Comparing Five Specimens

	Set	*1*		*2*		*3*		*4*		*5*		*6*		*7*		*8*		*9*		*10*	
	Run	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*
Position in holder	Up	S	A	S	B	S	C	S	D	A	B	A	C	A	D	B	C	B	D	C	D
	Down	A	S	B	S	C	S	D	S	B	A	C	A	D	A	C	B	D	B	D	C

more general with regard to levels and factors (*5, 13*). In an *n*-factor two-level-each-factor experiment all possible combinations of factor-levels would result in $2^n - 1$ separate effects being estimated. These would include not only those identified with each single factor, or main effects, but also any combined factor effects, or interactions, that might exist. Clearly two- and three-factor interactions could and in many cases do exist and are of paramount importance. However, higher-order interactions can often legitimately be ignored by the experimenter in comparison with the main effects. The fractional replication design recognizes this and sacrifices estimates of the higher order combined effects to obtain a reduction in the number of individual experiments required to obtain unbiased estimates of the remaining factors. The information available about the system under study, determines what combined effects can be ignored and hence leads to a particular fractional set.

This technique can dramatically reduce the total number of experiments, especially when the number of factors is large.

As an example consider an experiment directed toward screening fuel-element specimens in which type of burnable poison, geometry of specimen, burnup rate, location of poison in element, i.e. cladding vs. core, and method of fabricating poison in element are all to be investigated. We want to choose for further development the specimen type that results in a fairly flat net reactivity curve, providing that structural properties are comparable. We propose to irradiate the sample specimens over several different exposure levels and perform the statistical analysis on the sum of squares of deviations of observed reactivity (as determined by the R.M.F.) from a corresponding idealized reactivity curve. There will be two levels for each of the five factors a, b, c, d and e. A particular experiment is conveniently represented by a combination of lower-case letters corresponding to the factors, the presence of the letter indicating the second level for the factor, the absence of the letter indicating the first level of the factor. The symbol 0 is used to denote all factors at the first level. With this notation the full factorial experiment for this study can be neatly represented in Table 5.

If combined effects involving three or more factors can reasonably be assumed to be negligible, we can reduce this set by a factor of two to the set of 16 experiments in Table 6.

If all combined effects can be assumed negligible (i.e., only the main effects of the individual factors are of particular significance) a four-fold reduction in the full factorial can be effected. A particular set of eight experiments that would accomplish the estimation of the unbiased effects of each of the five factors under this assumption is given in Table 7.

Thus we see that a priori information has a direct bearing on the total number of experiments required to realize the objectives.

Physical problems associated with arranging specimens in the sample

Gadolinium, Gadolinium chlori
Galactonic acid lactone, Gala
loride, G
ethanolam
Gallium c
Gallocyanin, Gallophenine, Ga
Hydrol
acid, G
ethanol
acetate, Germyl bromide, Ger
Germanium metal, Germanium mo
te
te
Gi
Gitoxigenin, Gitoxin, Gliadin
Glucoascorbi
acid d, Gluc
Glucosaminic
Glucose-o-carboxyanilide, Glu
Glucos
mercap
ethylxa
pentaacetate, Glucose sodium
Glucose thioureide, Glucose u
Glucosides, Glucos
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TABLE 5—2^5 Full Factorial Set

0	d	e	de
a	ad	ae	ade
b	bd	be	bde
ab	abd	abe	abde
c	cd	ce	cde
ac	acd	ace	acde
bc	bcd	bce	bcde
abc	abcd	abce	abcde

TABLE 6—½ Replication 2^5 Factorial Set

0	be	ad	abde
de	bd	ae	ab
ce	bc	ac	abce
cd	bcde	acde	abcd

TABLE 7—¼ Replication 2^5 Factorial Set

0	ace
de	acd
bc	abe
bcde	abd

holder within the test spaces have for the sake of simplicity been avoided in this example; however, in the actual problem these must be recognized and appropriate adjustments made in the design. This can certainly be done through the blocking techniques of the previous examples or by increasing the number of factors to include the so-called nuisance parameters of the experimental complex. The need for appropriate statistical design becomes even more apparent when these factors are included.

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- The unit illustrated is used in the salvage severance of obsolete pipelines. In actual use the cutting head is suspended in the "hot" area and is operated by remote control. It is controllable in a manipulator "wrist action" for positioning between manifolded pipe headers. In less than 10 seconds it will cut 4" O.D. x .226 wall Inconel pipe at room temperature. Your inquiry on units of this type or for the development of other special equipment involving high pressure hydraulics would be welcome.

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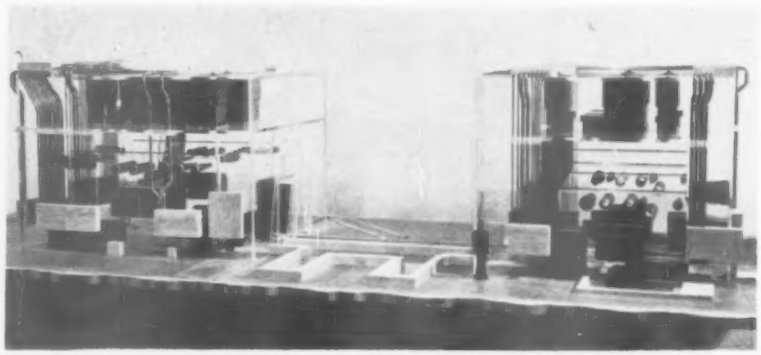
Gamma Facilities of the United States

For a second time we bring up to date our listing of gamma facilities in the United States and Canada (NU, July '58, p. 108; NU, July '59, p. 88). The following table indicates new facilities installed and changes made since our last listing. Changes are in italics. Since no changes and no new facilities have been indicated in Canada, we feel that our three listings, taken together, constitute an accurate description of all facilities in the two countries today. There is no attempt to include medical irradiators.

What will be the largest and most elaborate irradiator in the U. S. does not appear yet in the table. It is the High Intensity Radiation Development Laboratory for which ground was recently broken at Brookhaven National Laboratory; a model appears in the figure. The eventual plant will have two caves, one designed as a work cave and the other as an irradiation cave with storage well and conveyor. Both caves can eventually be used for irradiations as can a shielding canal that connects the two. The system is capable of putting to use as much as 2-million curies of Co^{60}, but the initial loading will probably be about 500,000 curies.

* * *

Miss Leida Blanco supplies the table from the NUCLEONICS *card file, which we intend to keep continuously up to date.*



HIGH INTENSITY RADIATION DEVELOPMENT LABORATORY abuilding at Brookhaven will have two elaborately equipped 25 × 25-ft caves, hold up to 2×10^6 curies of Co^{60}

Gamma-Facility Characteristics—Answers to a NUCLEONICS Questionnaire

Facility	*Location*	*Source strength, date (Curies of Co^{60} except as otherwise noted)*	*Maximum dose rate (10^6 r/hr)*	*Maximum volume (ft^3)*	*Public use?*	*Clearance required?*	*Classified experiments?*	*Personnel, policy, facilities**
New Listings								
Amherst College	Amherst, Mass.	500, May '54	0.005	2	Yes	No	No	PR
Bausch & Lomb Optical Co.	Rochester, N. Y.	1,000 Nov. '59	0.5	0.01	No	No	No	CO
Boeing Airplane Co.	Seattle, Wash.	400 Oct. '60	0.1	2	Yes	No	Yes	PCW
Columbia Southern Chem. Corp.	Barberton, Ohio	1,100 Feb. '60	0.13	0.1	No	No	No	LR
Convair	Fort Worth, Texas	100c Cs^{137} Jan. '59	0.1	600	Yes	No	Yes	PCWMB
		3,000 Jan. '58	3	0.5	Yes	No	Yes	PCR
Dow Chemical Co.								
Pig Facility	Midland, Mich.	1,000 1955	0.3	0.018	No	No	No	PLR
Cave Facility	Midland, Mich.	28,000 1956	0.5	1760†	No	No	No	WMBLR
Pig Facility	Freeport, Texas	300 1955	0.06	0.026	No	No	No	PL
Cave Facility	Freeport, Texas	1,200 1956	0.29	14	No	No	No	PL
Duke University	Durham, N. C.	312 Feb. '59	0.11	~0.018	No	No	No	PR
Emory Univ.	Atlanta, Ga.	160 Mar. '60	0.00015	‡	Yes	No	No	
Florida State Univ.	Tallahassee, Fla.	250 Feb. '60	0.18	0.037	Yes	No	No	CLR
		120c Cs^{137} Nov. '60	0.04	§	No	No	No	
Frankford Arsenal	Philadelphia, Pa.	3,000 Oct. '60	0.9	0.10	No	Yes	Yes	P
General Mills	Minneapolis, Minn.	2,338 Mar. '60	0.835	0.23	No	No	Yes	P
Georgia Institute of Tech.	Atlanta, Ga.	12,000c Cs^{137} Jan. '60	1.4	0.058	—	No	Yes	PCMB
Goodyear Tire & Rubber Co.	Akron, Ohio	3,600 Jan. '60	0.27	25	No	No	No	PCWOLR
Iowa State Univ.	Ames, Iowa	508 1955	—	—	No	No	No	—
Lockheed Aircraft Corp.	Palo Alto, Calif.	1,000 Jun. '59	2	0.003	Yes	No	Yes	PCWTMBLR
Mass. Institute of Technology	Cambridge, Mass.	26,000 Jan. '61	0.5	2.6	Yes	No	No	PCR
Mellon Institute	Delmont, Pa.	150 Mar. '60	0.06	0.01	No	No	No	
		900 Mar. '60	0.36	0.01	No	No	No	
Monsanto Chemical Co.	Dayton, Ohio	660 Sep. '60	1.5	0.07	No	No	No	PLR

Facility	*Location*	*Source strength, date (Curies of Co^{60} except as otherwise noted)*	*Maximum dose rate (10^6 r/hr)*	*Maximum volume (ft^3)*	*Public use?*	*Clearance required?*	*Classified experiments?*	*Personnel, policy, facilities**
National Bureau of Standards	Washington, D. C.	~1,000 Sep. '60	~0.5	0.01	Yes	No	No	P
Naval Air Material Center	Philadelphia, Pa.	12,500 Jul. '60	1.0	0.13	No¶	No	No	PLR
University of New Hampshire	Durham, N. H.	148 Mar. '60	0.135	0.1	No	No	No	OM
Pennsylvania State Univ.	Quehanna, Pa.	7,200 Apr. '60	1	0.8‖	Yes	No	Yes	PCOM
Pittsburgh Plate Glass Co.	Pittsburgh, Pa.	1,200 Mar. '59	0.13	0.2	No	No	No	—
Purdue University	Lafayette, Ind.	860 Oct. '56	0.32	0.015	Yes	No	No	PC
Quantum, Inc.	Cheshire, Conn.	200 Aug. '55	0.057	0.007	Yes	No	No	PCOR
Shell Chemical Co.	Torrance, Calif.	18,600 Aug. '59	8	0.66	No	No	No	LR
Union Carbide Chemicals Co.	South Charleston, W. Va.	1,000 Jan. '60	0.1	1	No	No	No	PTLR
Union Carbide Corp.	Parma, Ohio							
Lead-Shielded		2,000 Jun. '57	1.2	0.4	No	No	No	LR
Underwater		3,500 May '59	2.0	1	No	No	No	LR
U. S. Dept. of Agriculture	Orlando, Fla.	480 Apr. '57	0.09	0.09	Yes	No	No	PCM
	Sebring, Fla.	1,800** Sep. '57	0.1	0.09	Yes	No	No	PCM
	Tifton, Georgia	450 Aug. '57	0.1	0.09	Yes	No	No	PCM
	Honolulu, Hawaii	416 Jul. '57	0.09	0.09	Yes	No	No	PCM
	New Orleans, La.	1,000 Jun. '57	1.5	0.003	Yes	No	No	PC
	Corvallis, Oregon	83 Mar. '58	0.03	0.006	Yes	No	No	PC
	Brownsville, Texas	600 Sep. '57	0.1	0.09	Yes	No	No	PCM
	Kerrville, Texas	600 Sep. '57	0.1	0.09	Yes	No	No	PCM
University of Tennessee	Memphis, Tenn.	160	0.00054	—	No	No	No	
University of Virginia	Boyce, Va.	200 Mar. '60	0.000128	††	Yes	No	No	PC
Univ. of Wisconsin	Madison, Wis.	800 Sep. '60	4	(5 ml)	No	No	No	R
Changed Listings								
Atomics International	Canoga Park, Calif.	*4,000‡‡ May '60*	*3*	1	No	No	Yes	PCLR
Battelle Memorial Inst.	Columbus, Ohio	*2,000 Jan. '60*	*0.8*	~700	Yes	No	Yes	PCOMLR
Brookhaven National Lab.	Upton, New York	*~30,000*	*1*	1	No	No	Yes	PLR
California Research Corp.	Richmond, Calif.	*440 Mar. '60†*	0.24	0.014	No	No	Yes	PCL
Cities Service R & D Co.	Cranbury, N. Y.	*2,500 Mar. '60*		*0.14*	No	No	No	*PCWML*
Columbia Univ.	New York, N. Y.	*2,500 Mar. '60*	*~1*	*0.14*	No	No	No	*PCWML*
Univ. of Georgia	Athens, Ga.	145 Dec. '57	*0.04*	§§	No	No	No	P
Hanford Atomic Prod. Operation, General Electric Co.	Richland, Wash.	Fuel elements	—	0.25	No	Yes	Yes	PCL
		~5,100 Oct. '59	1.22	0.25	No	Yes	Yes	PCL
		~18,000 Oct. '59	4.2	0.25	No	Yes	Yes	PCL
University of Louisville	Louisville, Ky.							
Source A		*727 Feb. '59*	*0.357*	0.004	Yes	No	No	PCR
Source B		*777 Feb. '59*	*0.480*	*0.004*	*Yes*	*No*	*No*	*PCR*
The Martin Co.	Baltimore, Md.	*700 / 2,200 Sep. '60*	*0.3*	¶¶	Yes	No	Yes	*PCMBL*
University of Michigan Phoenix Laboratory	Ann Arbor, Mich.	*4,000 Mar. '60*	*0.72*	20	Yes	No	No	PCWTMLR
Naval Air Material Center	Philadelphia, Pa.	*1,800 Apr. '59*	0.5	~0.06	No	No	No	P
Radiation Applications, Inc.	L. I. City, N. Y.	*1,000 Jan. '60*	*0.30*	6.75	Yes	No	Yes	*PCLR*
Rensselaer Polytechnic Inst.	Troy, N. Y.	*~600 Sep. '60*	*0.2*	*0.25*	Yes	No	No	PCWMLR
Sinclair Research Laboratories	Harvey, Ill.	*17,000 Apr. '59*	*1*	1	No	No	No	*PWMBL*
Socony-Mobil Oil Co.‖‖	Dallas, Texas	15 Aug. '56	0.008	—	No	No	No	PM
Socony Mobil Oil Co.	Pennington, N. J.	*8,000*** Apr. '60*	2	—	No	No	No	PWMLR
Stanford Research Institute	Menlo Park, Calif.	*2,000 Jan. '60*	*0.5*	1	Yes	No	Yes	PCMBLR
Texaco Inc.†††	Beacon, N. Y.	*22,600 Jul. '60*	1	—	No	*No*	*No*	PWML
Union College	Schenectady, N. Y.	1,120 May '58	*0.5*	*0.02*	*Yes*	No	No	PCLR

* P = personnel to conduct experiments, C = contract research, W = viewing window, T = closed-circuit television, O = other viewing equipment, M = manipulators, B = conveyor, L = liquid-flow equipment, R = refrigeration equipment.

† Rods can be placed in any convenient form.

‡ This is an outdoor field, diameter 50 ft.

§ Source is in shuttered cask. Samples may be of any size.

¶ Available to govt. contractors by special arrangement

‖ Limited only by irradiation container; source configuration is flexible; pool size is 8 × 10 ft.

** 3 units, 600c each.

†† Fenced area 150 × 200 ft.

‡‡ Gamma facilities provided by the Atomic Energy Commission.

§§ Maximum dose occurs in 1.5-in.-diameter, 6-in.-long stainless steel cylinders with Co^{60} in periphery.

¶¶ Variable in pool.

‖‖ Formerly listed under "Magnolia Petroleum Co."

*** Facility is designed to handle fuel elements which will be obtained for later experimentation.

††† Formerly listed under "The Texas Company."

Gamma-Irradiation Facilities in Japan

By AKIBUMI DANNO
Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken, Japan

Facilities for studying radiation chemistry in Japan have increased in number remarkably during the past five years. With increasing research in this field, intense gamma-ray sources and electron accelerators have become familiar. About 30 irradiation facilities currently in use by universities, research and industrial establishments in Japan contain more than 1,000 curies of Co^{60} each. For radiation sources Co^{60} is most used, although separated fission products such as Cs^{137} are chosen in a few cases. All of these radionuclides are imported from foreign countries. The figure gives the location of the irradiation facilities in our country and the table describes each one. Most of these facilities are crowded in and around the big cities of Tokyo and Osaka.

Of the facilities listed in the table, 28 indicate that they are available for public use, and 20 say that they are not. Facilities not publicly available are generally used by the owner companies. The remaining 22 facilities indicate that special permission is required for their use.

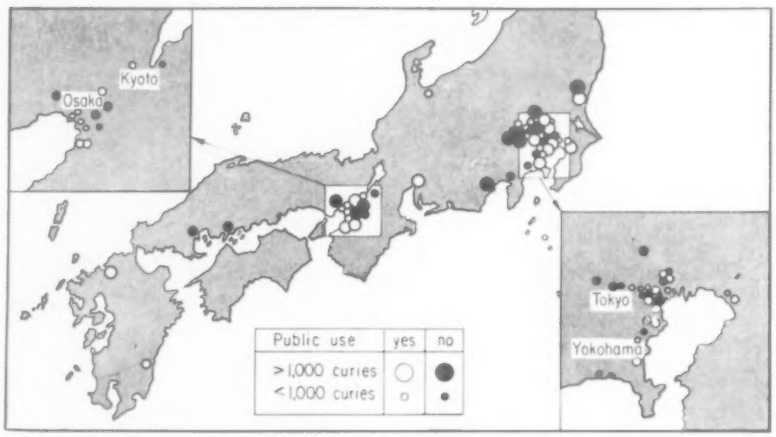
The facility at the Japan Atomic Energy Research Institute has the largest source—10,000 curies of Co^{60}. This facility was designed in Japan and completed in August, 1958.

Shapes of radiation sources are divided into three types: point, line and cylinder. Several kinds of irradiation equipment can be divided into three systems: container, cave and semi-cave systems. In the container system the irradiation is carried out in the cavity of a radioactive enclosure, and in the cave system the radiation source is brought up from a storage pit, and the irradiation is carried out in the whole space inside the cave. The intermediate system is called "semi-cave" for convenience.

No attempt has been made to include medical installations and particle-irradiation facilities. The latter are located at many radiation-chemistry laboratories in Japan and usually are used in parallel with gamma facilities.

* * *

The author wishes to express his sincere thanks to the Japan Atomic Industrial Forum, Inc., for permission to cite the results of an Investigation conducted in 1959 and 1960 by the Committee on Radiation Chemistry of the Forum.



Gamma Irradiation Facilities in Japan

Facility	*Location*	*Source strength, date (curies of Co^{60} except as otherwise noted)*	*Maximum dose rate (10^6 hr/hr)*	*Source type* diameter (mm) length (mm)*	*System type†*	*Public use?*	*Permission required?*	*Personnel, policy, facilities‡*
Asahi Chemical Industry Co., Ltd.	Itabashi, Tokyo	475 Aug. '58	0.3	C	Cn	No	No	PCR
Fermentation Research Inst.	Inage, Chiba	100 Aug. '58 100 Mar. '60	0.004	P	Ca	Yes	Yes	PO_mVR
Government Forest Experiment Station	Meguro, Tokyo	880 Mar. '59	0.05	C 160 280	Ca	Yes	No	PWVR
Governmental Industrial Research Inst., Nagoya	Kita-ku, Nagoya	485 Apr. '57	0.07	C 74 170	Ca	Yes	No	$PCWTO_pVR$
Governmental Industrial Research Inst., Tokyo	Meguro, Tokyo	3,866 Aug. '58	0.52	C 118 200				
		332 May '57	0.05	C 100 300	Ca	Yes	Yes	$PCWO_pV$
		2,000 June '59	0.25	C 130 250				
		217 Mar. '60						
Hitachi Ltd., Central Laboratory	Kitatama, Tokyo	1,500 June '58	1.0	C	Ca	No	No	PCWTMVR
		50 July '56	0.01	P				
Ind'l Rsch. Inst., Kanagawa Prefecture	Kanagawa, Yokohama	1,570 June '58	0.52	C	Ca	Yes	No	$PCWMO_pR$
Industrial Research Inst., Osaka Prefecture	Nishi-ku, Osaka	360 Sep. '57	0.16	C 40 150	Cn	Yes	No	PO_m
Institute of Physical and Chemical Research	Bunkyo, Tokyo	1,250 Aug. '58	0.44	C 80 180	Ca	Yes	Yes	PCWVR
		270 June '58	0.5	P				
Japan Association for Radiation Research on Polymers	Bunkyo, Tokyo	1,200 Mar. '58	0.34	C 85 170	Se	Yes	Yes	PCR
	Neyagawa, Osaka	1,156 Oct. '57	0.7	C	Ca	No	Yes	PCO_mVR

Gamma Irradiation Facilities in Japan (Continued)

Facility	*Location*	*Source strength, date (curies of Co^{60} except as otherwise noted)*	*Maximum dose rate (10^6 hr/hr)*	*Source type* diameter (mm) length (mm)*	*System type†*	*Public use?*	*Permission required?*	*Personnel, policy, facilities‡*
Japan Atomic Energy Research Inst.	Tokai, Ibaraki	11,230 Dec. '57	2.20	C 100 250	Ca	Yes	No	$PCWO_pMBLVR$
		500 Mar. '58	0.10	L				
Keio Univ., Dept. Gen. Education	Kohoku, Yokohama	46 Aug. '58	—	P	Cn	No	No	P
Kyoto U., Inst. Chemical Research	Takatsuki, Osaka	200 Feb. '57	0.07	L	Cn	Yes	Yes	PVR
Inst. Textile Chemistry	Sakyo-ku, Kyoto	2,400 June '58	0.24	C 100 250	Ca	Yes	Yes	PO_mR
Kyowa Fermentation Industry Co., Ltd.	Shibuya, Tokyo	100 July '57	0.01	L	Ca	No	No	PV
		72 Aug. '58						
Kyushu Univ., Faculty of Agriculture	Hakozaki, Fukuoka	3,000 Oct. '60	1.0	C 80 100	Ca	Yes	Yes	PCO
Kurashiki Rayon Co., Ltd.	Kurashiki, Okayama	330 Dec. '56	0.07	C	Cn	No	No	PO_mR
Mitsubishi Rayon Co., Ltd., Research Inst.	Otake, Hiroshima	50 Aug. '57	0.03	P	Ca	No	No	PO_mVR
		500 May '60	—	C				
Miyazaki Univ.	Miyazaki, Miyazaki	150 Aug. '60	—	P	Se	Yes	Yes	PO_m
Matsushita Elec. Ind. Co., Ltd.	Kitakawachi, Osaka	100 Mar. '60	—	P	Se	No	No	PCO
National Hygienic Laboratory	Setagaya, Tokyo	170 Oct. '58	0.0002§	P	Ca	Yes	Yes	PO_mVR
National Inst. Animal Health	Kitatama, Tokyo	130 Mar. '58	0.02	P	Ca	Yes	No	PWVR
National Inst. Agricultural Science	Hiratsuka, Kanagawa	105 June '57	0.005	P	Ca	No	No	PWVR
		41 June '58						
National Inst. of Genetics, Japan	Mishima, Shizuoka	50 May '56	0.002	P	Ca	No	No	PWVR
		Cs^{137}200 Dec. '59	0.06	P				
National Inst. Radiological Science	Chiba, Chiba	3,000 Mar. '60	—	C	Ca	No	Yes	PCWVR
Nihon Rayon Co., Ltd.	Uzi, Kyto	315 Oct. '60	—	C				
Nippon Atomic Industry Group Co., Ltd.	Kawasaki, Kanagawa	3,000 Nov. '60	—	C	Ca	No	No	PCWTV
Nippon Telegraph and Telephone Public Corp.	Tokai, Ibaraki	4,000 Sep. '60	1.0	L	Ca	No	Yes	PCMBRVL
		3,000 Sep. '60	—	L				
Nitsuto Inst. Chemical Research	Urawa, Saitama	1,000 Mar. '60	0.1	C 100 250	Ca	No	No	$PCWO_pR$
Osaka City Univ.	Kita-ku, Osaka	220 June '60	—	C				
Osaka Industrial Research Inst.	Ōyodo, Osaka	10 Dec. '56		P	Cn	Yes	No	PC
		5 Mar. '57						
Osaka Municipal Tech. Research Inst.	Kita-ku, Osaka	600 Oct. '57	0.40	C 75 200	Ca	Yes	No	PCO_mV
Osaka U., Faculty of Engineering	Toshima, Osaka	100 Mar. '57	0.30	P	Cn	Yes	Yes	PR
Radiation Laboratory	Sakai, Osaka	3,000 May '58	0.60	C 64 280	Ca	Yes	Yes	$PCWO_pMBLR$
				174 280				
		1,000 June '59	0.2	C 119 240				
		1,000 Mar. '60	0.12	L				
		1,000 June '60	—	L				
Radiation Central Laboratory, Osaka Prefecture	Sakai, Osaka	3,800 Mar. '60	—	C	Ca	Yes	No	PCWMR
		1,000 Mar. '60						
Sericultural Experiment Station	Suginami, Tokyo	120 May '58	0.1	P	Ca	Yes	Yes	PWVR
Shizuoka Univ.	Shizuoka, Shizuoka	1,000 May '60	—	C	Ca	Yes	Yes	PCOVR
Showa Electro-Chemical Industry Ltd.	Ōta, Tokyo	255 July '58	0.1	C	Ca	No	No	PCOV
		410 Nov. '59	0.2	L				
Sumitomo Atomic Energy Industries Ltd.	Takarazuka, Osaka	2,000 Aug. '59	0.6	C	Ca	No	No	PCOVR
Teikoku Rayon Co., Ltd.	Kitatama, Tokyo	1,000 Aug. '60	0.2	C	Ca	No	No	PCWVR
Textile Research Inst.	Kanagawa, Yokohama	50 Sep. '57	0.0008	P	Ca	Yes	Yes	PCO_mVR
		400 Mar. '60	0.04	C 50 200				
Tokai Reg'l Fisheries Research Lab.	Chuō, Tokyo	400 Jan. '58	0.07	P	Ca	Yes	Yes	PO_mV
Tokyo Agriculture Univ.	Setagaya, Tokyo	140 Jan. '58	0.05	P	Cn	No	Yes	PV
Tokyo Inst. of Technology	Meguro, Tokyo	280 Oct. '57	0.40	P	Cn	Yes	Yes	PCR
Tokyo Metropolitan Isotope Center	Setagaya, Tokyo	1,060 Aug. '59	0.50	C	Ca	Yes	Yes	$PCWTMO_pR$
Tokyo Metropolitan Univ.	Setagaya, Tokyo	50 July '56	0.04	P	Se	Yes	Yes	PO_mV
		50 July '57	0.01	P				
		50 July '59	—					
Tokyo Shibaura Electric Co., Ltd., Matsuda Research Laboratory	Kawasaki, Kanagawa	100 June '57	0.05	L	Ca	Yes	Yes	PCWTMV
		1,300 Aug. '58	0.45	C				
U. of Tokyo, Engineering Faculty	Bunkyo, Tokyo	1,200 Oct. '57	0.40	C 92 150	Ca	No	Yes	PCO_pVRL
Tokyo Univ. of Agriculture and Technology	Koganei, Tokyo	27 Aug. '56	0.0003§	P	Ca	No	No	PO_mR
		25 July '58						
Tokyo Univ. of Fisheries	Minato, Tokyo	1,000 Mar. '58	0.24	C 80 100	Ca	Yes	Yes	PO_mV
Toyama-ken Nōji Shikenjō	Toyama, Toyama	100 July '58	0.001	P	Ca	Yes	Yes	PWV
Tōyō Rayon Co., Ltd., Research Dept.	Ōtsu, Shiga	100 Jan. '57	0.10	P	Ca	No	No	PWO_pVR
		280 July '59	0.12	C				
Tōyō Spinning Co., Ltd., Chemical Research Inst. for Textiles	Moriguchi, Osaka	100 Jan. '57	0.01	P	Ca	No	No	PCO_pVRL
		1,000 Jan. '59	0.20	C				

* P = point, L = line, C = cylinder.

† Cn = container, Ca = cave, Se = semi-cave (intermediate between container and cave).

‡ P = personnel to conduct experiments, C = contract research, W = viewing window, T = closed-circuit television, O = other viewing equipment, (O_p is periscope, O_m is mirror), M = manipulators, B = conveyers, L = liquid-flow equipment, V = ventilation, R = refrigeration equipment.

§ At 1 meter.

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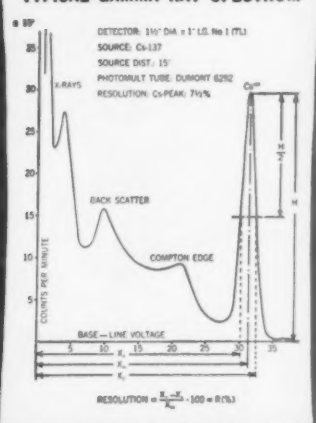

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Radionuclides Measure Nose-Cone Wear in Flight

By E. R. RATHBUN, *Cook Research Laboratories, Chicago, Illinois*

Missile nose cones wear away as they re-enter the earth's atmosphere. We have developed a method that uses radionuclides to measure this ablation. As illustrated in Fig. 1, we determine the material remaining by measuring the counting rate from radionuclides painted down the side of a plug made of nose-cone material inserted in the cone itself. To count this activity we use miniature instrumentation inside the nose cone: a scintillation probe, a counting-rate meter and a power supply that is transistorized.

Our experiments have shown that the wear rate of the nuclide is truly representative of nose-cone wear since the meter measures the ablation rate only at the location of the thin,

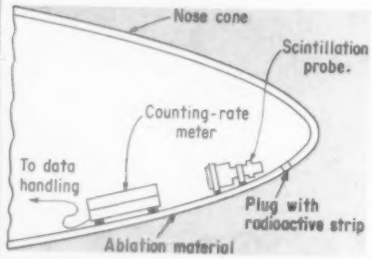


FIG. 1. NOSE-CONE ablation on contact with atmosphere is determined with help of radioactive strip. Counting rate determined by probe and counting-rate meter tells remaining thickness of cone material

narrow strip and interfering processes such as diffusion do not have time to become important.

Using Radioactivity

In ground tests Na^{24} served as the radionuclide to test the ablation meter. In missile flights, however, we use Co^{60} because of its longer half-life. The amount of radionuclide in any experiment varies because each experiment requires a different geometry. In general, the radioactive material varies between a few tenths of a millicurie and 1–2 mc, painted in a strip a few millimeters wide down the side of the cylindrical plug. To make sure that the radioactivity is uniformly distributed along the strip, we check it by careful assay with a scintillation counter before we fit the plug into a hole in the nose cone.

Inside the nose cone a scintillation probe placed fairly close to the plug measures the radioactivity that comes from it.

The relationship between counting rate and remaining nose-cone thickness varies from experiment to experiment because of the different geometries required in each experiment. To get the relationship we placed small disks coated on the edges for 2–3 mm with radioactive material in the holes where the test plugs would eventually be inserted. We then removed these one by one and recorded the counting rates as the thickness was reduced; this gave us calibration curves for each experiment (Fig. 2).

The counting-rate range is 500–10,000 cps, far above background at sea level. In flights, however, we include a second probe and counting-rate meter in the missile to measure

Withstanding Missile Flight

The brutal stresses that missile components are subjected to could harm our instrument system. To make sure that the instruments can withstand the shock and vibration, we check their performance before and after running them through the following tests:

- 5–55 cps, 0.065 in. double-amplitude vibrations on two axes for 15 min
- 55–2,000 cps, 10-g vibrations on two axes for 15 min each
- 30-g, 11-millisec shock
- 50-g, 30-sec continuous acceleration.

cosmic-radiation background and internal effects. These counts serve as a correction factor for the ablation measurements; we can subtract the cosmic ray count from the meter count to obtain a difference that is truly representative of the radioactivity remaining in the plug.

Instrumentation

The probe that counts radioactivity contained in the strip is in turn connected by a high-voltage signal cable to a counting-rate meter mounted some distance behind the probe. Transistor power supplies give the required potential. Since the instrument system must withstand the vibrations and shock of space flight it must undergo the survival tests that are outlined in the box on page 100.

Scintillation probe includes a NaI(Tl) crystal and a DuMont 6407 photomultiplier. An emitter-follower stage built into the base of the probe, couples the output impedance of the phototube to the amplifier input (Fig. 3).

Counting-rate meter. Input pulses from the scintillation probe travel to an amplifier and driver unit to trigger a blocking oscillator (Fig. 4). Input amplitudes of 0.01–50 volts

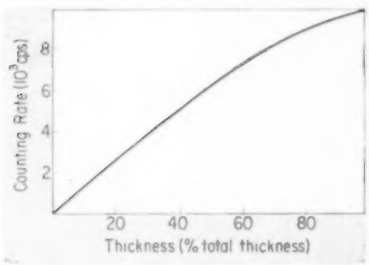


FIG. 2. CALIBRATION CURVE for ablation meter is obtained with stack of radioactive disks that simulate plug. Gamma absorption is nearly linear in thin sections; in thick sections this is not true

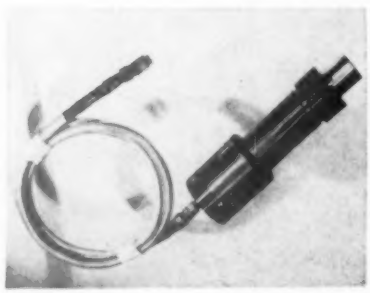


FIG. 3. SCINTILLATION PROBE views plug with radioactive strip and sends signals to counting-rate meter

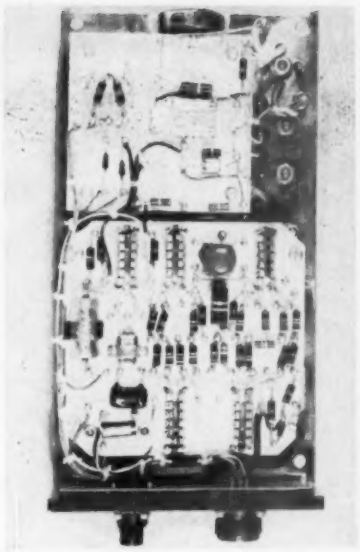


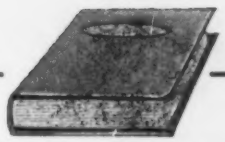
FIG. 4. COUNTING-RATE METER uses subminiature vacuum tubes in measuring signals from scintillator

give an output signal that is amplitude limited and differentiated so that it comes to the plate of the blocking oscillator as a moderately fast pulse with an amplitude of ~5 volts. This signal is sufficient to trigger the blocking oscillator. The blocking oscillator output passes to an amplifier for squaring and aplitude limiting and then through a cathode follower to drive the low-impedance, capacitive integrating circuit. The integrating circuit has constants such that 10,000 cps gives a 5-volt d-c output. For easy adjustment, the voltage appears across a potentiometer that selects reference values within the instrument range. Thus one can compensate for slight inaccuracies inherent in the preparation of the radioactive strip painted down the side of the plug.

Power supplies are transistor-regulated d-c to d-c units that furnish 150 volts d-c for the counting-rate meter and 1,500 volts d-c for the photomultiplier in the probe circuit. The total input current is 1.5 amp at a nominal 28 volt d-c. Designed to operate properly with 26–30-volt input, the unit tests safely from 24 to 32 volts.

* * *

The generous and loyal support of Mr. C. R. Memhardt, Dr. J. A. Bjorkland, and the engineering staff of the Cook Research Laboratories is gratefully acknowledged. This work was supported by the Army Ballistic Missile Agency, Redstone Arsenal, Huntsville, Alabama, under Contract No. DA-01-021-ORD-4974.



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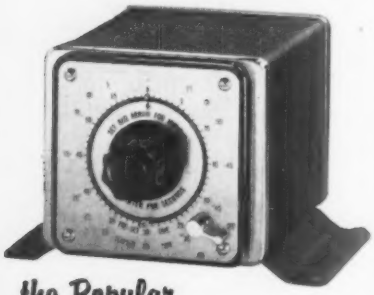

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Radiation Biology

Edited by J. H. MARTIN (Academic Press Inc., New York, N. Y., 1959, $11.00, xi + 304 pages)

Reviewed by RAYMOND E. ZIRKLE, Committee on Biophysics, University of Chicago, Chicago, Ill.

This book gives the Proceedings of the Second Australasian Conference on Radiation Biology held in Melbourne during December 1958. It contains a foreword by Sir F. MacFarlane Burnet and 29 technical contributions averaging about ten pages each. Several of these are didactic, e.g., the lead-off article, "Radiation Dose—Macroscopic, Microscopic and Sub-Microscopic Aspects" (L. H. Gray), and one on "Imperfections Induced in Solids by Fast-Particle Irradiation" (P. G. Klemens). On the other hand, most of the contributions are essentially reports of the individual researches of the authors. Accordingly, the book is primarily for the advanced worker in radiation research.

Although a fair fraction of the papers deal with basic aspects of radiation actions on various biological and inanimate systems, many are frankly oriented toward practical aspects of radiation injury. Thus, there are two papers on detection and measurement of radioactive fallout, two on distribution and metabolism of fission products, and one on radiation-induced leukemia. There are also several contributions aimed at development of methods for treating radiation injury through studies on experimental animals.

The more basic studies present a wide spectrum. There are three papers on radiation chemistry, two on radiation physics, two on embryological effects, four on the influence of oxygen and other factors on radiobiological sensitivity, etc. The final paper is a thought-provoking one by Gray entitled "Radiobiological Mechanisms at the Cellular Level: Lines of investigation which have been opened up by recent technical developments."

The papers, in general, are clearly written, show signs of careful editing, and are enhanced in interest by the discussion printed after each. The four contributed by Gray and the four by J. F. Loutit maintain the high standards that have become so familiar to their contemporaries in radiation research. The book is attractively designed and contains a subject index. It should be available to all professional and pre-professional investigators of radiation effects.

Who's Who in Atoms

Edited by A. W. HASLETT (Vallancey Press, London, England, 1960, $35.28, 983 pages)

The first edition of this book, published in 1959, provided us with an extremely useful reference guide of participants in the nuclear field. Now this work has been enlarged by 4,000 additional names and published in a second edition that has grown so in size over the first that it comprises two volumes. It contains over 12,500 listings of nuclear scientists and engineers from more than 70 countries. In addition, the editors have added over 300 cross-references.

The information listed for each person follows the same form as in the first edition. One learns about the education of the scientist, his published books and papers, the societies to which he belongs, and his address. In addition, a new section "nuclear interests" has been added. This new edition is an indispensible, quick and concise reference guide to workers and those interested in the nuclear field.

Electronics and Nucleonics Dictionary

By NELSON M. COOKE and JOHN MARKUS (McGraw-Hill Book Co., Inc., New York, 1960, $12.00, 543 pages)

With definitions of over 13,000 terms, this dictionary fills a useful need in the electronics field. But the nucleonics words, which seem largely to have come from ASME's "Glossary of Terms in Nuclear Science and Technology," do not include such terms (sought at random) as burnable poison, containment, glove box, meat, NaK, NELIA, radiolytic, Zircaloy, or pressure suppression. Of 60 nuclear words for which this reviewer sought definitions, he found only about 20. Illustrative of the electronics orientation of this dictionary is the fact that the word "poison" is defined as "a contaminating substance that impairs the efficiency of a material. It may reduce phosphorescence in a luminescent material, reduce emission of a cathode surface, or reduce the reactivity of a nuclear reactor by absorbing electrons unproductively."

Thus, while the book appears complete in its definitions of electronics terms, and it will be useful to people

in nuclear instrumentation work, it is not nearly as adequate for the nucleonics field. An up-to-date and complete nuclear glossary has yet to be published.—JJD

Books Received

International Dictionary of Applied Mathematics (D. Van Nostrand Co., Inc., Princeton, N. J., 1960, $25.00, 1,173 pages). The dictionary defines terms and discusses the mathematical methods used in 31 fields of physical science and engineering—including the nuclear fields. An important new feature of the dictionary is the foreign-language index at the back of the book that lists in alphabetical order the French, German, Russian and Spanish equivalents of the words and terms that are discussed in the dictionary. The book should prove to be a very useful reference book for any scientist or layman.

Also of Note

Radioisotope Teletherapy Equipment (International Directory) contains specifications, features and prices of 47 teletherapy units available from manufacturers throughout the world. The directory represents the IAEA's second step in providing technical information on radioisotopes. Previously, they have published an international directory of radioisotopes. 121 pages, 1959, *International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

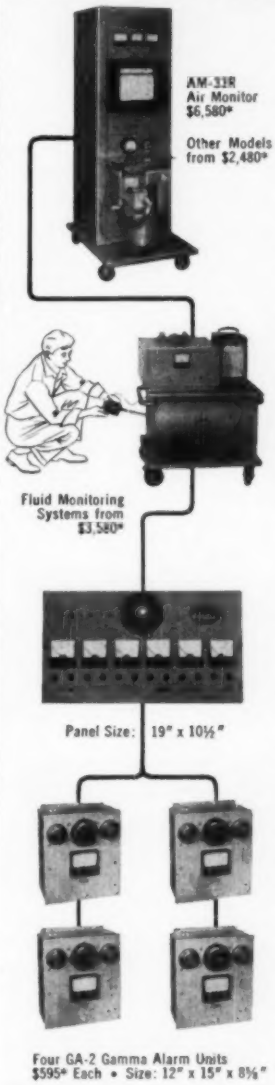
Use of Radioisotopes and Supervoltage Radiation in Radioteletherapy contains the recommendations adopted by a study group under the IAEA and WHO for use of radiotherapy in cancer treatment. The recommendations include, among other things, evaluations of radiations; training of personnel; protection requirements; international cooperation; geographical distribution of equipment; economic aspects of radiotherapy equipment; and a list of 14 topics suggested for future research. *International Publications, Inc., 801 Third Ave., New York 22, N. Y.*

Properties of Hydrided Yttrium (APEX-558), by D. S. Parker, reports physical and mechanical properties (for 4.8 and 5.4×10^{22} hydrogen atoms/cm^3) determined in a GE-ANPD program. 23 pages, 50¢. *Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C.*

Monitoring Systems

DESIGNED, BUILT AND BACKED BY NMC INDIANAPOLIS, INDIANA

What is your radiation monitoring problem? Airborne particulates . . . gaseous or liquid radiation . . . or gamma area radiation? NMC equipment can monitor any one or all with individual units or complete systems. The system shown here presents data at each station and on a control room follow meter panel. It warns of caution and alarm levels; can even operate emergency controls.



AIR MONITORS

NMC air monitors offer many exclusive advantages. For example, Model AM-33R shown here detects and identifies long half-life emitters directly, almost immediately, with one detector. Other monitors require five hours or more for identification, due to the natural radon progeny. The four NMC models are . . .

MODEL	CHANNELS	FILTERS	ACTIVITY DETECTED
AM-2A	1	Fixed	α, $\beta\gamma$ or γ
AM-3A	1	Moving	α, $\beta\gamma$ or γ
AM-22R	3	Fixed	α and $\beta\gamma$ Shows ratio of $\beta\gamma/\alpha$
AM-33R	3	Moving	α and $\beta\gamma$ Shows ratio of $\beta\gamma/\alpha$

FLUID MONITORS

The NMC fluid monitoring system detects radioactivity in gas or water at MAC levels. Used with an NMC air monitor, it measures activity of the gaseous component of the discharge from the air monitor. Contamination and a separate pumping system are eliminated by employing the air pumping system and filter mechanism of the air monitor. The fluid system includes the FMS-1 shield with 30 liter sampling chamber, and two detectors—GM or NaI scintillation—operating in parallel; the LCRM-2M logarithmic count ratemeter with built-in bell and alarm lights; and portable EA graphic recorder.

FOLLOW METER PANELS

Each monitoring station can be connected to a follow meter panel in the central control room with inexpensive unshielded standard electric code wiring. There's a meter for each station to show the radioactivity being detected, and lights to indicate caution and alarm levels. The bell sounds for an alarm condition at any station. Multipoint recorders and remote emergency controls may be connected to the panel.

AREA MONITORS

Each of the four GA-2 units shown here is a complete monitoring station that indicates and reports unusual or excessive gamma radiation. It mounts on the wall and wires to any 110-volt circuit, eliminating the central power supply required by other systems. Each GA-2 has an amber and red light, bell, indicating meter, and complete alarm system. Units readily adapt to a complete system. They connect to follow meters and graphic recorders; are interchangeable without the usual installation matching and calibration. They are not sensitive to temperature, line voltage changes or external electro-magnetic radiation. The amber light is also a fail-save device, signaling component failure. An auxiliary power supply for each GA-2 is available.

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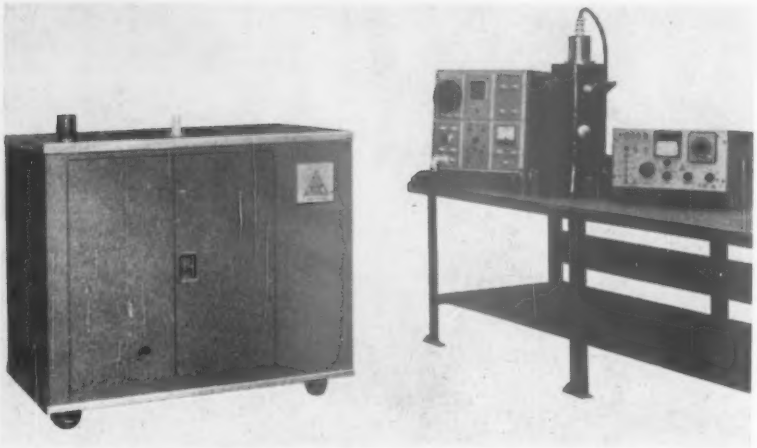
Nuclear Measurements Corp.
2460 N. Arlington Avenue • Indianapolis 18, Indiana
International Office: 13 E. 40th Street, New York 16, N.Y.
NMC INDIANAPOLIS



Neutron Activator Produces 10^8 neutrons/sec

RCL Model 70001 Neutron Activator uses the *d-t* reaction to generate 14.3-Mev neutrons. Principal parts of activator are: source cabinet (above left) containing pulse transformer, deuterium supply, accelerator tube and vacuum pump; multichannel analyzer, shield and detector (center); control cabinet (far right). Pulse transformer with 5-μsec pulse width provides acceleration potential (200 kev max at 10 amp). Deuterium gas is supplied to tube by a needle valve and accelerated to a 2-in. stainless-steel target covered with evaporated zirconium loaded with tritium. A two-stage mechanical pump maintains the 10^{-4}-mm Hg pressure range necessary for neutron production.—Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill.

400-Channel Analyzer

Model 34-12 combines compactness with low-power consumption and high reliability. Memory divides into four 100-channel or eight 50-channel subgroups for successive measurements without readout. Standard reference spectrum or background can be stored in half the memory and then transferred to the other half without being affected.—Radiation Instrument Development Laboratory, Inc., 61 E. North Ave., Northlake, Ill.

Hinged 100-Ton Press

Hydraulic C frame-type press is designed for compressing beryllium at Lawrence Radiation Laboratory. Hydraulically loaded counteracting cylinders at back compensate for pressure and give <0.020-in. spread. Platen stroke is 16 in.; distance beween platens in open position is 48 in., in closed, 16 in. Platen speed is 23 in./min; pressing speed is 4.5 in./min and return speed is 29 in./min. Press operation is automatic with manual over ride for each function.—Rucker Co., Oakland, Calif.

Portable Scaler

Transistor glow-tube scaler (above), $19 \times 12\frac{1}{2} \times 7$ in., provides 30-hr operation per charge; external battery charger also gives 115 volt a-c operation. Scaler includes regulated high-voltage supplies and ratemeter. Jewel-escarpment timer maintains 1-min timing interval within 0.1%. Other models are available for external 6- or 12-volt d-c, 115-volt a-c operation.—Troxler Laboratories, Box 5253, Raleigh, N. C.

Portable Iridium Units

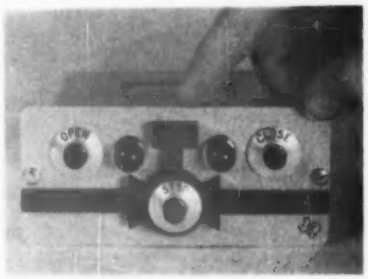
Five radiography cameras, designed for panoramic and internal radiography, have capacities of 10, 25, 35, 50 and 100 curies of iridium-192. The machines range from 50 to 100 lb. Iridium-192 is useful in radiographing from $\frac{1}{4}$ in. to over 3 in. of steel or from $\frac{3}{4}$ in. to over 9 in. of aluminum.—Radionics Inc., Lafayette and Water St., Norristown, Pa.

Life-Support System

System (above) protects handlers of toxic missile fuel, but can be adapted to radiation environments. Main parts: protective suit, helmet that replaces cumbersome face mask and won't fog up, back pack containing liquid-air storage vessel, pressure gage, ejector for circulating air, heat exchanger for cooling recirculated air and trap for collecting solids and excess moisture. System supports one man for two hours without recharging.—Garrett Corp.,Los Angeles 45, Calif.

X-Ray Spectrometer

N-1281 spectrometer has a system gain stability of better than 0.25% per day and linearity of better than 0.1%. System has both linear rate meter coupled to recorder and high-speed printing decade scaler and crystal controlled electronic timer for recording.—Hamner Electronics Co., Inc., P. O. Box 531, Princeton, N. J.

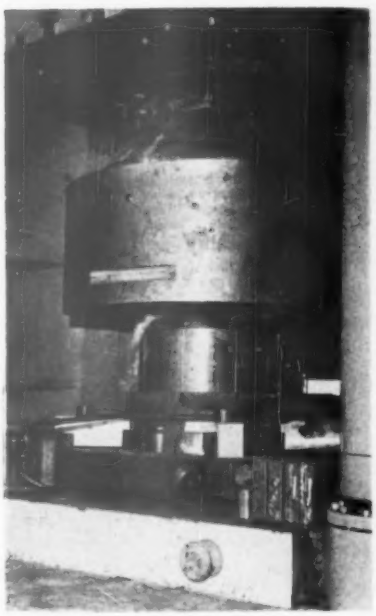


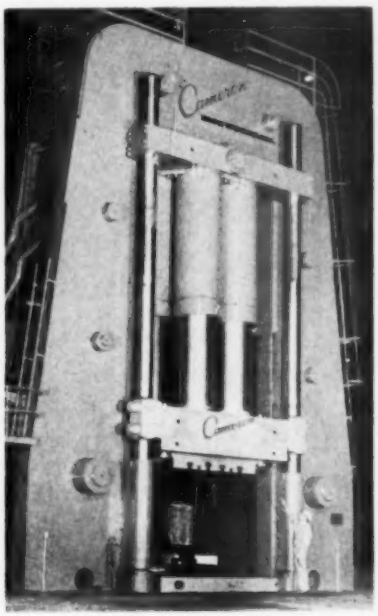
Remote Control Unit

New instrument gives remote open-stop-close or on-off control and status indication of power-operated devices. Two wires connect remote point and central control location where either incandescent or high-intensity neon bulbs are used. Maximum loop-line resistance can be 100 ohms for incandescent or 2,000 ohms for neon indicators. Standard field unit controls up to 2-amp coils at 480 volts. Higher capacities are available.—Texas Instrument Inc., 3609 Buffalo Speedway, Houston 6, Texas.

Composite Tubing

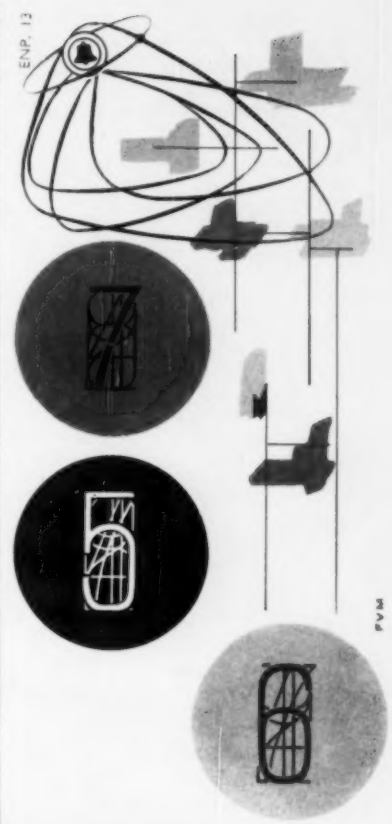
A composite of stainless steel inside and carbon steel outside provides corrosion-resistant tubing. An inseparable high-strength metallurgical bond is formed between the two types of steel. Corrosion resistance is increased by cathodic protection from metal combination, increased thermal conductivity and decreased thermal expansion of composite tubing. Tubing is produced by method that combines Ulam and hot extrusion process.—Allegheny Ludlum Steel Corp., Oliver Building, Pittsburgh 22, Pa.





20,000 Ton Forging Press

World's largest multiple-ram forging press will forge nuclear-reactor, jet-engine, missile and turbine components. Frame is 50-ft high, 31-ft wide and platen is 12 × 12 ft. Press has 15 ft of daylight, stroke of 90 in. and maximum extrusion of 30 × 56 ft. Side rams exert 5,000 tons each, piercing rams exert 4,200 tons, push-back rams have gross of 940 tons, net stripping force is 400 tons, and bottom knockout punch is 650 tons.—Cameron Iron Works, Inc., Houston, Texas.



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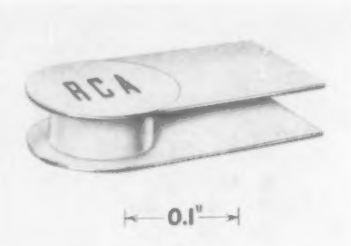
Reference thermocouple oven houses separate reference junctions for 48 measuring thermocouples weighing <8 lb. Temperature of the junctions is held constant within 0.5% for a wide range of ambient temperatures. Unit can be used with a-c or d-c power.—George Kelk Ltd., 5 Lesmill Rd., Don Mills, Ontario.



Tunnel Diodes

Three new germanium types, 1N3128 (low-current type for pulse-repetition rates up to 100 Mc), 1N3129 (intermediate speed, rates up to 500 Mc), 1N3130 (ultra-high speed, rates up to 1,000 Mc) and one gallium-arsenide diode, 1N3138 (high speed, rates up to 1,000 Mc) are offered. Tunnel diodes have switching speeds to $\frac{1}{5}$ mμsec, peak currents of 5, 20, and 50 ma controlled to ±5%, wide operating temperature range of −65 to +150° C. They withstand immersion for 10 sec at 275° C.—Radio Corporation of America, Somerville, New Jersey.

Magnetic Preamplifiers

A series of low-level, high-gain units detect 10 mv d-c. Preamplifiers require less than 3 watts of 115 volt ±10% power. Reliable preamplifiers operate for years without adjustment or maintenance.—Acromag, Inc., 22515 Telegraph Rd., Southfield, Mich.

Tiny Resistance Thermometer

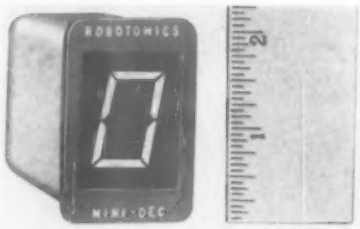
Model S31 that is a precision resistance thermometer 0.138 × 0.4 in., has an accuracy of better than 0.05 ohm or 0.05° F. Sensing element is chemically pure platinum; unit is vibration and shock damped. Operating range is from −100 to 400° F with resistance change of ~1 ohm/° F; linear deviation is <1% of full range.—Minco Products, Inc., 740 Washington Ave. N., Minneapolis 1, Minn.

Scale-of-Ten Tubes

Four new decade counting tubes are offered: CK6909 and CK6910 operate up to 100 kc, have electrical readout from any cathode lead; CK6802 and CK6476 operate at 4 kc, offer electrical readout at *0*, *5*, *8* and *9* cathode leads.—Raytheon Co., 55 Chapel St., Newton, Mass.

Radiation Detector

EDU-12 evaporation-detection unit has 1,000-ml capacity and needs 2–3 hr to concentrate 90% of radioactive material on a 2-in. planchet. Made of heavy duty aluminum, EDU-12 measures $7\frac{1}{2} \times 7\frac{1}{2} \times 3$ in. weighs 20 lb and has controlled, self-contained heating unit.—Technical Services Department, Nuclear Corp. of America, Denville, N. J.



Miniature Counter

Transistor Model 1401, 200-kc decade counter (above) has 1-in.-high in-line, in-plane numerical display. 7-oz. counter has stacked modular-printed circuit boards protected by aluminum dust cover. Paired pulse resolution is <5 μsec, input −10 volts at 1.5 μsec, output to drive other similar decades, electrical reset to zero. Total power consumption is 1.6 watts. Dimensions are $1\frac{7}{16} \times 2\frac{1}{8} \times 4\frac{1}{4}$ in. —Robotomics, Inc., 4624 E. Garfield, Phoenix, Arizona.

Color-Coded Fuel Elements

For better in-position identification, Sylcor is color-coding aluminum

fuel elements, such as those used at the University of Buffalo. Anodized color side-plates come in a variety of colors and engraved fuel-element serial numbers on the color plates gives sharp contrast for improved clarity.—Sylcor, Hicksville, N. Y.

Portable Survey Meter

Victoreen 440 detects low-level beta and gamma radiation as low as 1 mr/hr in one of five sensitivity ranges from 0 to 300 mr/hr. Response is ±15% from 6.5 kev to 1.2 Mev; accuracy is ±10%. The detector, which weighs 5½ lb and is 10 × 7½ × 4 in. in size, operates on four D-flashlight cells for over 100 hr. —Victoreen Instrument Co., 5806 Hough Ave., Cleveland, Ohio.

Cement Mixer for Wastes

A new cement mixer helps dispose radioactive wastes at Consolidated Edison. Waste materials are put together with cement into steel drums and then capped with cement. The turbine mixer handles one cubic yard of cement and waste material and is remotely operated.—T. L. Smith Co., 2835 N. 32 St., Milwaukee, Wis.

Information on Nickel

High-Temperature Engineering Section of INCO will provide technical information on use of nickel alloys at high temperatures and will advise on selecting materials for high-temperature applications.—International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.

LITERATURE AVAILABLE

Short Form Catalogue. 8 pp.; EMI Electronics, Ltd., Hayes, Middlesex, England.

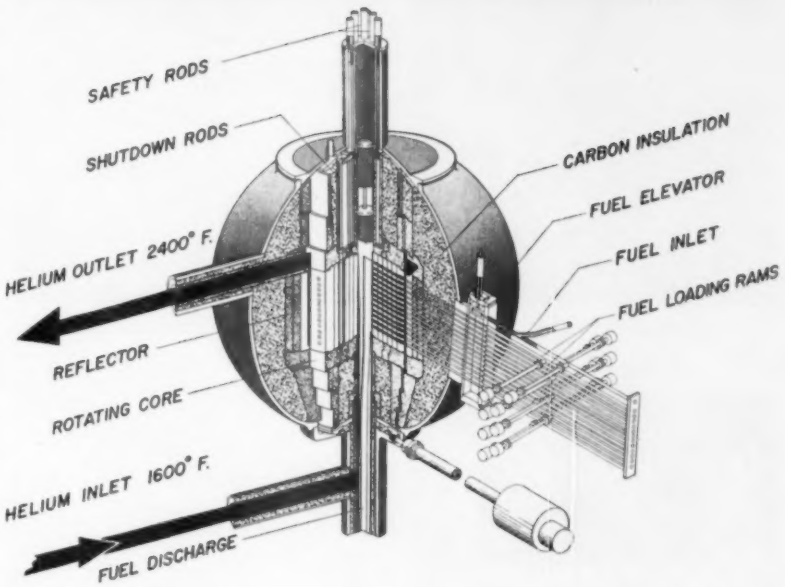
Amplifier Analyzer. Bulletin AN 6502. 4 pp.; Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Pulse-Height Analyzer. 4 pp.; Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

Process Instrumentation; Measurement and Control. 8 pp.; Nuclear Chicago Corp., 333 E. Howard Ave., Des Plaines, Ill.

TURRET

an unclad fuel reactor experiment at Los Alamos



Fuel systems suitable for advanced concepts in power reactor design are being actively explored and evaluated by the Los Alamos Scientific Laboratory. Interest is particularly high in developing systems in which high utilization of natural resources is obtained by plutonium-fueled breeders and in developing systems in which the cost of fuel refabrication is minimized through the use of simple, mobile fuels. As a step in the evolution of more economic fuel, Turret, a high-temperature gas-cooled reactor experiment using unclad fuel elements, will soon be under construction.

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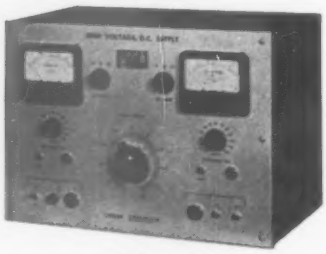

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Products and Materials

Department starts on page 104

All Nuclear Accessories. 32 pp., Atomic Accessories Inc., 813 W. Merrick Rd., Valley Stream, N. Y.

Nuclear Products for Industry. 22 pp.; Catalog #625. Isotopes Specialties Co., Box 688, Burbank, Calif.

1960–1961 Catalog of Instruments and Filters. 43 pp.; Gelman Instrument Co., 106 N. Main St., Chelsea, Mich.

Bendix and Nuclear Energy. 12 pp.; Bendix Corp., Fisher Bldg., Detroit 2, Mich.

Nuclear Engineers and Consultants to the Free World. 7 pp.; Internuclear Co., 7 N. Brentwood Blvd., Clayton 5, Mo.

Computing β-ray Absorption and Back-scattering. 4 pp.; Nuclear-Chicago Corp., 333 E. Howard Ave., Des Plaines, Ill.

Safety Enclosures. 32 pp.; Kewaunee Scientific Equipment, 4042 Logan St., Adrian, Mich.

Millimicrosecond Instruments. 1 p.; Lumatron Electronics, Inc., 116 County Courthouse Rd., New Hyde Park, N. Y.

PNP Germanium Madt Transistors—2N501 & 2N501A. 2 pp.; CBS Electronics Information Services, 100 Endicott St., Danvers, Mass.

Gas-Flow Counters. 2 pp.; Atomic Accessories Inc., 811 W. Merrick Rd., Valley Stream, N. Y.

AccuRay On-Stream Composition Analysis. 11 pp.; Industrial Nucleonics Corp., 650 Ackerman Rd., Columbus 2, Ohio.

Space Age Metals. 24 pp., Lunex Co., Pleasant Valley, Iowa.

Corrosion-Resistant Pipe and Tubing of Nickel-Alloy-Bonded Steel. 8 pp.; M. L. Sheldon & Co., 350 Lexington Ave., New York 16, N. Y.

Metal Products for the Nuclear Industry. 10 pp.; BSA House, 54 St. James Street, London, England.

INDUSTRY NOTES

● **American Machine & Foundry Co.** has licensed Pye Ltd., a world-wide British electronics company, to manufacture and market AMF nuclear research and training reactors in the U. K. and Ireland. The AMF-Pye agreement extends AMF's activities in the nuclear field throughout the British Commonwealth, excluding Canada, and in Iraq, Jordan and Egypt. Pye Ltd. produces radio and television transmitting and receiving equipment, and is already established in the nuclear field. It has a number of contracts in the U. K. for fuel-inspection and remotely-controlled equipment. In 1956, AMF had licensed Pye to manufacture and sell its master-slave manipulators.

● A new department to emphasize generation of electricity directly from nuclear reactor heat without use of rotating machinery has been created by **Atomics International,** Calif. Ned S. Rasor and Donald E. McKenzie have been named director and assistant director. Projects planned for the department include development of thermionic devices, novel lightweight batteries and fuel cells.

● **Linde Co.,** a division of Union Carbide Corp., has been awarded a $31-million contract through 1966 to supply 60-million lb of liquid hydrogen to the National Aeronautics Space Administration's west coast research-development program which includes Rover. This contract is in addition to a five-year contract calling for 3.3-million lb to be supplied to NASA by Linde's Torrance, Calif. plant. Linde was among three companies to bid. It will manufacture the hydrogen at a new Fontana, Calif. plant, scheduled to be finished and in production by mid-1962. Until then, Linde will deliver liquid hydrogen to meet contract terms from its West Palm Beach Fla., facilities.

● **Ebasco Services, Inc.,** New York City, has received a contract from AEC for architect-engineering services, estimated at $4-million, for the 250-Mwth, $24-million Advanced Test Reactor at the National Reactor Testing Station in Idaho. **Babcock & Wilcox Co.,** New York City, will subcontract to Ebasco on design of the nuclear portion. A separate construction contract will be awarded next May.

● **Nuclear Materials and Equipment Corp.** has received an AEC operating license for its plutonium facility at Leechburg, Pa. Numec will use the facilities primarily to carry out its Pu-oxide fuel-cycle contract with AEC, and will also fabricate Pu-beryllium neutron sources.

ACQUISITIONS. **Baird-Atomic, Inc.,** Cambridge, Mass., has purchased controlling interest in a Dutch nuclear instrument company: Electronisch Kernfysisch Apparatenfabriek, N. V., The Hague, Holland. EKAF, previously 100% owned by Bouvy-Zout, Holland, will now be known as **Baird-Atomic Holland, N. V.** Company officials stated the move was made to step up activities in the European market, and also to produce for U. S. consumption a few instruments where labor costs are a major factor. Baird-Atomics also operates its own sales subsidiary in Kleve, West Germany.

COMPANY MOVES. **Tatnall Measuring & Nuclear Systems, Ltd.,** Canada, a subsidiary of the **Budd Co.,** has been renamed Budd Instruments Ltd. Offices, formerly in Toronto, are now located at 170 Donway West, Don Mills, Ontario . . . **Isotopes Specialties Co.,** a div. of Nuclear Corp. of America, has expanded its sales department to include a representative on the eastern seaboard from Northern Virginia throughout New England. William Johnson and Associates of Mt. Lake, N. J., was named as representative.

FINANCE. **Nuclear Chicago Corp.** reported its best quarter in its history for orders, shipments and earnings for the period ending Nov. 30. The company also disclosed plans for expanding its plant this spring, adding about 25,000 sq ft to the production area—a 50% increase. Under its process-control instrumentation program, N-C will increase its staffs at five branch offices. N-C also reports that its 23rd subcritical assembly was installed at Northeastern Univ., Boston, Mass., making the company "the largest supplier of these $15,000 devices."

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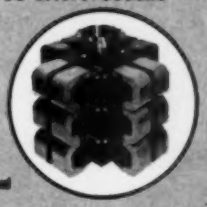

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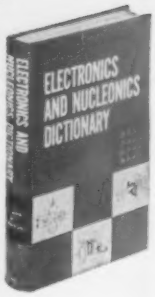

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NEWSMAKERS

Gordon O. Fraser has been appointed vice-president for exports of the International Group of the American Machine and Foundry Co. with responsibility for AMF overseas atomic sales. He joined AMF in 1958, after serving as assistant administrator of the U. S. Department of Agriculture's foreign agricultural service.

Fraser

Abraham Hyatt has been appointed the director of the National Aeronautics and Space Administration's office of Program Planning and Evaluation. He succeeds Homer J. Stewart, and was deputy director of NASA's Launch Vehicle Programs.

Gordon S. Brown, Dean of MIT School of Engineering, has been elected to the Board of Directors of Baird-Atomic, Inc., Cambridge, Mass. In 1948, he received the President's Certificate of Merit, the nation's highest civilian award, for advances made by MIT's Servomechanisms Laboratory.

Brown

William F. Hall and **Mortimer T. Beam** have joined the staff of the University of Buffalo's Nuclear Research Center. Both were formerly with the Curtiss-Wright Corp. Research div. at Quehanna, Pa. Hall was operations manager, Beam was in radiation protection. Hall will be manager of the Center's reactor when it begins operation in March; Beam will supervise health and safety.

Forest J. Remick, acting director of the Nuclear Reactor Facility at the University of Pennsylvania, has also been named acting director of the Curtiss-Wright Nuclear Research Laboratory at the University, Quehanna, Pa.

Kuan H. Sun and Chiang Kai-Shek

The 1960 Achievement Award of the Chinese Institute of Engineers of New York has been presented to **Kuan H. Sun,** manager of Westinghouse Electric Corp.'s Radiation and Nucleonics Laboratory for his "distinguished service in engineering and science." In 1959, Sun was granted a leave of absence from Westinghouse to accept a Fulbright professorship at Tsing-Hua University near Taipei, Formosa—an assignment from which he has since returned.

Lloyd V. Berkner has been elected first president of the Graduate Research Center, Dallas, Texas. The center has been without a president since it was formed, in 1957, by a group of leading businessmen to "advance knowledge in both the pure and applied sciences." Chairman of the board of trustees is **J. Erik Jonnson,** chairman of Texas Instruments, Inc. Berkner, after 10 years, resigned as president of Associated Universities, Inc. which operates Brookhaven National Laboratories for AEC. **Leland J. Hayworth,** vice-president of AUI and director of Brookhaven, has been appointed AUI's acting president.

Jerrold Zacharias, a member of President Eisenhower's Science Advisory Committee, has been retained by Sprague Electric Co. as a consultant. **Jerome B. Weisner** has been appointed to the company's board of directors. He is the director of the Research Laboratory of Electronics at MIT.

George W. Switzer, Jr., has been named manager Nuclear Energy div. of Gilbert Associates, Inc., Reading, Pa. Gilbert Associates holds subcontracts from the Westinghouse Electric Corp. for the Saxton, Pa. experimental nuclear reactor. Switzer will be responsible for Gilberts' engineering and design project work in the nuclear field.

Switzer

William Sjoborg, formerly with Curtiss-Wright, has been named to the senior staff at Quehanna and a research associate in the Nuclear Engineering dept. Penn State has leased the hot cell facilities of the laboratory to Martin Nuclear.

Brig. Gen. Austin W. Betts, Army Corps of Engineers, has been appointed director of the AEC's Military Applications div. He succeeds **Maj. Gen. A. D. Starbird,** who has been appointed division engineer of the North Pacific div. of the Army Engineers. Gen. Betts was director of the Advanced Research Project Agency of the Department of Defense.

William E. Ray has been appointed director of research of Dresser Products, Inc., Great Barrington, Mass. For the past five years, he was metallurgical consultant on submarine reactors at Knolls Laboratories, Schenectady, N.Y. Dresser specializes in research, development and processing of nuclear-space materials.

Ray

A Canadian, **Paul E. Gagnon,** has been appointed director of the International Atomic Energy Agency's division of Exchange and Training of Scientists and Experts.

Alan E. Over has joined Victoreen Instrument Co., Cleveland, Ohio, as assistant sales manager of its components div. He was formerly with the Union Switch & Signal div. of Westinghouse Air Brake Co.

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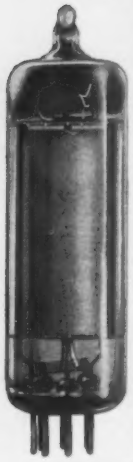

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NUCLEAR CALENDAR

Feb. 1–4—Annual Winter Meeting of the American Physical Society, New York City (*Hotel New Yorker*). Contact: K. K. Darrow, American Physical Society, 538 W. 120 St., New York 27, N. Y.

Feb. 16–17—Symposium on Materials for Nuclear Application, University of New Mexico, Albuquerque (*Student Union Building*). Sponsors: American Society for Metals (Albuquerque and Los Alamos Chapters), and the University of New Mexico. Contact: A. W. Snyder, Radiation Effects div., Sandia Corp., Albuquerque, New Mexico.

Feb. 26–March 1—Pacific Electronic Trade Show, Los Angeles (*Great Western Exhibit Center*). Contact: Pacific Electronic Trade Show, 2216 South Hill St., Los Angeles 7, Calif.

March 10–11—The Second Annual Meeting of the Southeastern Chapter of the Society of Nuclear Medicine, Atlanta, Georgia. Sponsor: The Society of Nuclear Medicine. Contact: James C. Coberly, chief of radioisotope service, Veterans Administration Hospital, 4158 Peachtree Rd., N. E., Atlanta 19, Georgia.

March 21–30—139th Meeting of the American Chemical Society, St. Louis, Mo. Contact: A. T. Winstead, National Meetings dept., ACS, 1155 Sixteenth St., N. W., Washington, D. C.

March 27–31—Third Symposium on Temperature, Its Measurement and Control in Science and Industry, Columbus, Ohio (*Veterans Memorial Auditorium*). Sponsors: Instrument Society of America, American Institute of Physics, National Bureau of Standards. Contact: ISA, Meetings Service dept., 313 Sixth Ave., Pittsburgh 22, Pa.

April 4–6—International Symposium on Electromagnetics and Fluid Dynamics of Gaseous Plasma, Engineering Societies Bldg., 33 West 39th St., New York City. Sponsors: Institute of Radio Engineers, Aeronautical Sciences, and U. S. defense research agencies. Contact: Symposium Committee, Polytechnic Institute of Brooklyn, 55 Johnson St., Brooklyn 1, N. Y.

April 17–19—Seventh Instrument Society of America Symposium on Instrumental Methods of Analysis, Houston, Texas (*Shamrock-Hilton Hotel*). Contact: ISA, Meetings Service dept., 313 Sixth Ave., Pittsburgh, Pa.

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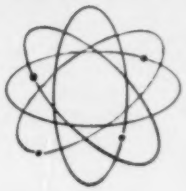

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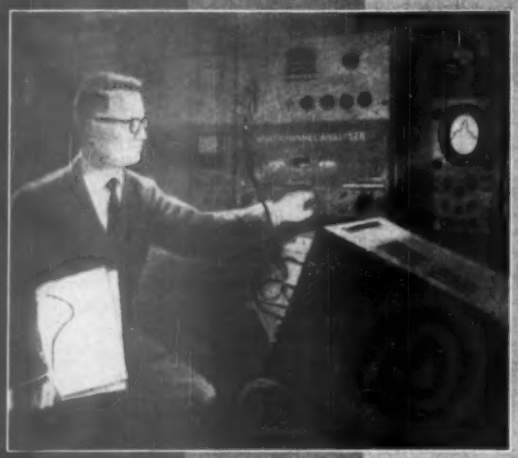

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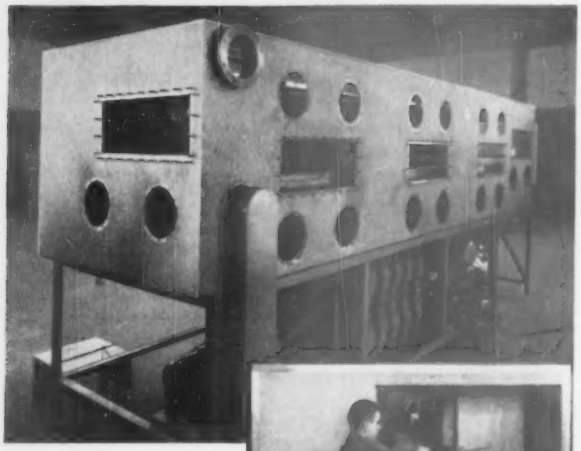

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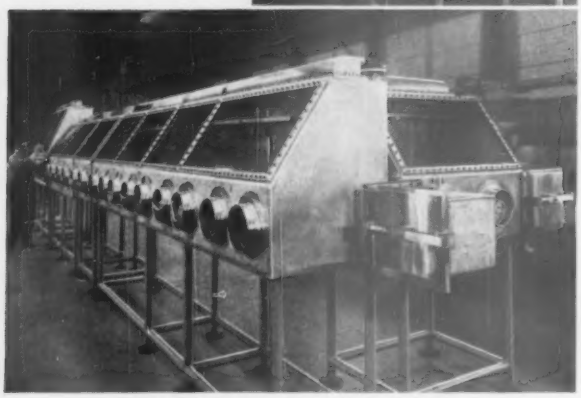

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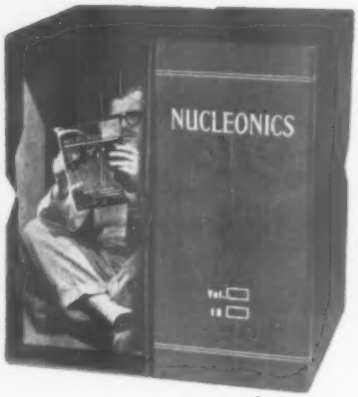

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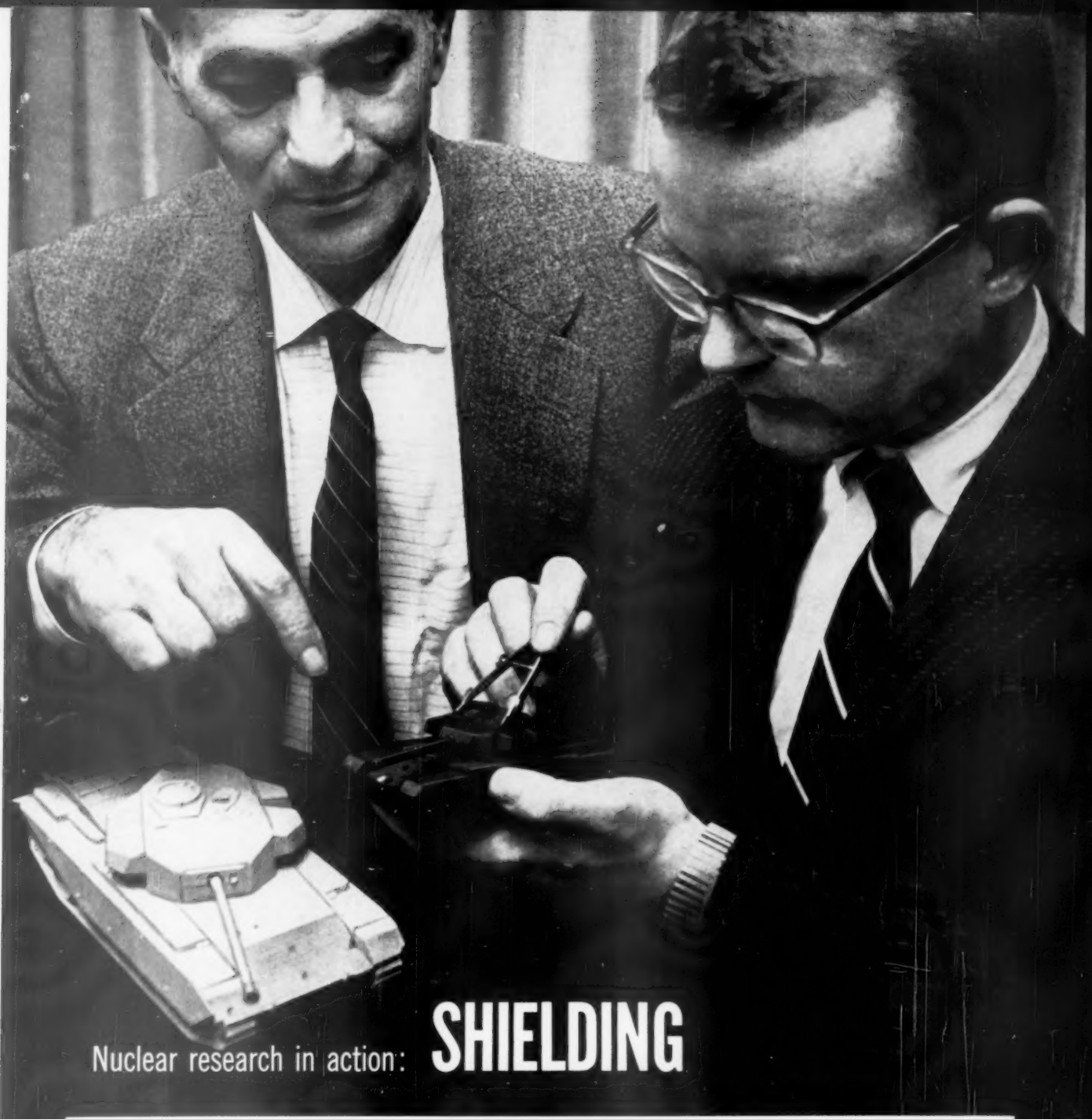

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